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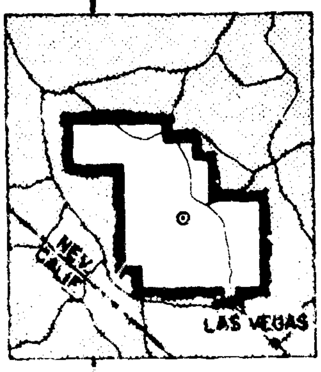

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Project 30.5

INSTRUMENTATION OF STRUCTURES FOR AIR-BLAST AND GROUND-SHOCK EFFECTS

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CIVIL EFFECTS TEST GROUP

Report to the Test Director

INSTRUMENTATION OF STRUCTURES FOR AIR-BLAST AND GROUND-SHOCK EFFECTS

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ABSTRACT

The objective of Project 30.5 was to provide instrumentation, electronic and self-recording, for obtaining air-blast and ground-shock loading and response of the structures employed by the various structures projects. Included was installation of transducers, recording of transducer signals, and presentation of the recordings as linearized time dependent plots of the measured variable in the specified appropriate units. A total of 127 recording channels was utilized; of these channels, 75 were used for electronic recording on magnetic tape, 37 were used for self-recording time-dependent gauges, and 15 were peak-indicating gauges.

A basic description of the instrumentation employed by the Ballistic Research Laboratories in taking the structural measurements for Projects 30.1, 30.2, 30.3, 31.4, and 31.5 is given. Self-recording gauges for measuring peak pressures, pressures vs. time, dynamic pressures vs. time, and displacement vs. time are described; electronic gauges for obtaining time-dependent records of pressure, dynamic pressure, acceleration, displacement, and earth pressure are described.

For each type gauge, details are given on the recording mechanism, transducer element, gauge mount, calibration, and data presentation. A plot of the field layout is also shown.

A tabulation indicating the general success of the instrumentation recording operations and a discussion of anomalies is presented. Finally, recommendations for more effective instrumentation practices are given.

PREFACE

Project 30.5 was instituted solely as an instrumentation service to various Armed Forces Special Weapons Project (AFSWP) and Federal Civil Defense Administration (FCDA) structures design agencies. Originally, no formal project was organized for this purpose, but, because the Ballistic Research Laboratories (BRL) electronic instrumentation is packaged in units of 20 recording channels each and must be protected by expensive blast shelters, it was apparent that efficient operation would often demand a sharing of facilities among the various agencies to be served by BRL instrumentation.

To minimize the complexities of the administrative and financial accountability that would occur if such an effort were not consolidated, a Memorandum of Understanding (Appendix A) between Field Command, AFSWP; FCDA; CETG; and BRL established a combined project (3.7/30.5) to accomplish structures instrumentation for the various AFSWP and FCDA agencies. The duality of the assigned project number is a consequence of the projects being jointly supported by AFSWP and FCDA. All AFSWP funding was to Project 3.7; whereas FCDA funding was to Project 30.5. Support of Project 3.7/30.5 was in proportion to the number of instrumentation channels supplied to each organization, the AFSWP share being 60 per cent and the FCDA share being 40 per cent.

This is a complete and detailed report on the Project 30.5 portion of the BRL instrumentation effort.

ACKNOWLEDGMENTS

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Chapter 1

INTRODUCTION

Among the various damaging aspects of a nuclear detonation, air blast is one of the subjects studied. Two approaches to such a study are necessary, one being an investigation of the characteristics of blast waves under various specified conditions and the other being an investigation of the effect of a given blast wave on various structures or structural components. This report is a discussion of the measurement techniques and procedures used by the Ballistic Research Laboratories (BRL) to enable the investigation of the loading or response, or both, of structural designs of several FCDA projects on Operation Plumbbob.

1.1 OBJECTIVE

The objective of the project was to provide instrumentation, electronic and self-recording, to obtain air-blast and ground-shock loading and response of structures for the various structures projects in the Civil Effects Test Group Programs 30 and 31.

The scope of the program included installation of transducers, recording of transducer signals, and presentation of the recordings as linearized time-dependent plots of the measured variable in the specified appropriate units. Measurements were obtained using both self-contained direct-recording units and remote-recording magnetic-tape units. A total of 127 recording channels was supplied; of these, 75 were magnetic tape, 37 were time-dependent self-recording, and 15 were peak-indicating.

1.2 BACKGROUND

The history of BRL participation in nuclear testing extends from Operation Sandstone. During that operation mechanical self-recording and peak-indicating gauges were used, but, beginning with Operation Greenhouse, various systems of electronic recording have been utilized. All measurements taken by BRL previous to Operation Upshot-Knothole (i.e., Operations Sandstone, Greenhouse, Buster-Jangle, and Tumbler-Snapper) were free-field measurements concerned with blast-wave characteristics. For Operation Upshot-Knothole, however, BRL obtained and rebuilt the Webster-Chicago magnetic-tape recording equipment used by Sandia Corporation during Operation Greenhouse. Extensive structures-instrumentation progress resulted from the use of this equipment.[1] Before Operations Teapot and Redwing, further improvements in this equipment were made, and during those operations the equipment was used for both structures measurements and free-field measurements. During Operation Teapot, several standard commercial recording oscillograph units were also used for recording data similar to that recorded on the Webster-Chicago equipment; however, these units did not prove to be as rugged, reliable, or versatile as the modified Webster-Chicago recorders.

Each Webster-Chicago electronic unit records 20 channels of information on a magnetic tape 35 mm wide. To each channel a phase-modulated information signal and a reference sig-

nal are supplied. Phase modulation is obtained by combining the 3750 cycle/sec amplitude-modulated output signal from the gauge with another signal of 3750 cycles/sec but 90 deg different in phase. The reference signal (7500 cycles/sec) is mixed with the information signal, and the two are amplified and recorded simultaneously on the same magnetic track. Thus the reference signal is subjected to exactly the variations in amplification or tape characteristics experienced by the information signal, and their relative phase is maintained unchanged. In addition, an Edgerton, Germeshausen & Grier, Inc. (EG&G) Blue Box was used to produce a sharp amplitude-modulated zero-time marker, which was recorded on one magnetic track set aside for that purpose.

The playback system later recovers the information from the magnetic tape by separating the reference and the information signals and applying them to a phase discriminator that produces an output voltage proportional in magnitude to the tangent* of the measured variable. Also, timing pulses are derived from the 7500 cycle/sec reference signal. The signal, the timing pulses, and the zero-time marker are then recorded on an oscillographic recorder to produce a final record.

During the operations prior to Upshot-Knothole, the disadvantages of electronic instrumentation for field work became apparent. Such systems were expensive, cumbersome to install, time-consuming to adjust, and often highly sensitive to adverse conditions normally encountered in field work. The desire for a more adaptable system led to several designs for completely self-contained mechanical gauges capable of recording pressure as a function of time for use during Operation Upshot-Knothole. The success of these gauges then prompted the design of standard models of a self-recording overpressure-time gauge and a dynamic pressure-time gauge.

In these, a precisely governed battery-operated motor rotates an aluminized glass disk. A stylus attached to a compact metal bellows element traces on the rotating disk a record of the dilations of the bellows as they are subjected to the pressures of the blast wave. In this way a time-dependent record of the blast pressure is impressed on the disk. The motor is set in operation by a signal received from a thermal- or photo-initiation circuit or remotely by wire from timing relays. Gauges, the essentials of which are described above, were used with great success during Operation Castle. Since then, the gauges have been refined in many minor, but important, aspects; they have been used with continuing success under a wide range of conditions during Operations Teapot and Redwing. Because of their relatively low cost, they may be used in larger quantities, as required in the field wherever anomalies are to be expected. Also, because of their ease of installation, ruggedness, and versatility, they may be reused on consecutive shots and rapidly adapted to changeable field schedules.

However, there are certain instrumentation measurements for which a better time resolution is required than can be provided by the self-recording gauges. In such cases electronic recording instrumentation must be utilized.

Extensive use was made of both electronic and self-recording gauges in this structures-instrumentation effort.

REFERENCE

1. J. J. Meszaros and J. I. Randall, Project 3.28.1, Operation Upshot-Knothole Report, WT-738, June 1953.

*Operation is normally in the linear portion of the curve of ϕ vs. tan ϕ (where ϕ is the measured variable); thus output is directly proportional to the measured variable.

Chapter 2

OPERATIONS

The instrumentation systems used in Operation Plumbbob were of two general types: electronic recording and self-recording. Both types were used to obtain a variety of required measurements for the various structures projects. Explicit and detailed coverage of the two recording systems is presented in the following order: (1) self-recording gauges; (2) electronic recording gauges; (3) transducers; (4) gauge mounts; (5) calibration; and (6) data presentation.

2.1 SELF-RECORDING GAUGES

2.1.1 Physical Configuration of Pressure-Time Gauge

The recording mechanism for the pressure-time gauges was enclosed in a heavy airtight case (Fig. 2.1), the top of which acted as a baffle plate. Holes were drilled in each baffle plate for housing the photocell and the thermal-initiator plunger. Holes were drilled also to allow the blast pressure to reach the recording capsule and for the gauge arming screw. The pressure hole was covered by a small screen to prevent the entrance of dirt and to assist in damping capsule oscillations. The recording capsule was mounted on the inner side of the baffle plate; near it, on the same side, was welded a short length of channel iron, which served as a chassis for the turntable assembly and initiation circuits (Fig. 2.2). The turntable assembly consisted of the motor, shaft, angular-contact ball bearings, and dural turntable. Also attached to the chassis was a star-cam counter, which limited the rotations of the turntable to a predetermined number.

The entire design of the recording mechanism was such as to reduce its sensitivity to acceleration. The use of the angular-contact bearings in the turntable assembly allowed the shaft to be secured against either axial or transverse motion, and the use of dural in the turntable and shaft reduced the distorting forces in these members.

Drop tests and shake-table tests showed satisfactory operation of the gauge at 50 g, in that latching relays did not release, motor speed was essentially unaffected, and turntable vibration was acceptably low. At higher accelerations, up to 80 g, motor speed varied up to 5 per cent, and often the glass recording disks broke.

2.1.2 Disks

The basic recording medium of the self-recording equipment was an aluminized glass disk or plate on which a trace of the motion of a mechanical transducer element was scratched by an osmium-tipped stylus. With accurate regulation of the manufacturing process by which the glass disk or plate was given its aluminum coating and with careful control of the recording-stylus pressure, trace widths of less than a thousandth of an inch could be obtained.

Two types of self-recording gauges were used: one utilized a stationary aluminized glass plate to record the maximum excursions of the sensing element; the other utilized a rotating glass disk to obtain a time-dependent record of the motion of the sensing element.

2.1.3 Drive Motor

The drive motor that turned the disk (Fig. 2.3), was an A. W. Haydon Company model A-5615 "chronometrically governed" d-c electric motor. It used a self-contained oscillating balance wheel to generate a simple-harmonic reference. The rotation of the motor was translated into simple-harmonic motion, and the phase of this was compared with the phase of the reference by a pair of electrical contacts, one of which was actuated by the reference generator and the other by the motor. The contacts were so arranged that, when closed, they directly bypassed a series resistor through which current to the motor was fed. The relative phase of the simple-harmonic motions of the two contacts was determined by the portion of a cycle during which the contacts, being simultaneously actuated, bypassed the resistor and, consequently, determined the total power delivered to maintain a constant speed of rotation.

Motors having rotational speeds of 3, 10, and 40 rpm were used, depending on the application and time resolution required. These were also the obtainable turntable speeds for all except the dynamic-pressure gauges. The latter incorporated a two-to-one speed reduction, which, with motor speeds of 10 and 40 rpm, gave turntable speeds of 5 and 20 rpm. The motor was powered by an 8-volt mercury battery capable of running the motor at full load and rated speed for over 6 hr.

2.1.4 Initiators

The motor was set in operation by one of two self-contained initiator circuits used simultaneously or, alternatively, by a signal transmitted by wire from a central control point with the self-contained circuits used for backup.

The self-contained circuits operated on reception of either thermal or visible radiation from the detonation. An electronic initiator, sensitive to the bomb light, used a cadmium sulfide photocell and latching relay circuit. The light was guided to the photocell by a vertical length of $^{5}/_{16}$-in. Lucite rod. The rod was ground to a 45-deg bevel at the end, where the light entered to allow more efficient light capture. Only the voltages produced by transient light pulses were amplified to close the relay. In addition to the control contact, the relay was fitted with a pair of contacts that, when closed, caused a high current to flow through the relay coil; this held the relay closed.

The second self-contained initiator consisted of a spring-loaded plunger held cocked by a thermal link made of two brass strips soldered together with low-melting-point solder and painted black. Thermal radiation falling on this initiator rapidly heated it; when the solder reached a temperature of 169°F, the brass strips parted and allowed the spring to press the plunger against a microswitch, thereby starting the motor.

2.1.5 Start-up Time

Because of inertia and the time needed for establishment of the proper phase relations in the governor, the motors do not reach a stable speed immediately. The 3-rpm motors reach their rated speed in 90 msec but oscillate about the value for an additional 300 msec. The 10-rpm and 40-rpm motors reach their speed gradually and without instability in 400 msec.

2.1.6 Hard-wire Initiation

All gauges used for diffraction studies in areas where blast arrival times are less than 400 msec were initiated previous to zero-time by a signal transmitted by wire from one of the BRL instrument shelters.* This signal was produced by the closure of a standard EG&G timing relay at minus 5 sec and was used to close the electrically latching relay normally used with the photocell. The operation of this relay was duplicated by a second relay at minus 1 sec. The self-contained initiating circuits were retained for backup in case the hard-wire signals failed.

*This requirement was placed on all gauges for Project 30.1. All other gauges supplied by Project 30.5 were either outside the 400-msec range or were for pressure measurements that did not require the accuracy of timing needed for diffraction studies.

2.1.7 Physical Configuration of Dynamic-pressure Gauge

The dynamic-pressure-time gauge was a Pitot-static tube that used separate pressure-sensing elements to record the stagnation pressure and the side-on pressure (see Figs. 2.4 and 2.5). A $^5/_{32}$-in.-diameter hole was drilled down the axis of the nose section to transmit the stagnation pressure to the appropriate capsule. Also, a $^1/_8$-in.-diameter hole transmitted the side-on pressure to the other capsule. The two capsules were mounted at right angles to one another in a hollowed-out portion of the nose section. The styluses of the two capsules were arranged so that both could make their traces on the same disk. The two traces were made at different radiuses, and events recorded by the two styluses appeared simultaneously on the disk but separated circumferentially by 90 deg.

The end of the nose section containing the recording mechanism screwed into a hollow cylindrical section, which contained the motor power supply and initiation circuits. Two pipe nipples were welded to the outside of the casing and, by means of pipe unions, served to attach the dynamic-pressure gauge to its mount.

The thermal initiator was similar to the one used for the pressure-time gauge, except that it used a phototube detector, a sensitive relay, and a mechanical latching relay. The initiator circuitry was all mounted on a plexiglas sled (Fig. 2.6) which fitted inside the casing. On the rear of the sled was mounted a panel with three switches and four pinjacks. This arrangement allowed a quick and complete check of all the gauge circuits and convenient arming of the gauge just prior to the test. After testing and arming were completed, the rear end of the hollow casing was sealed by an aluminum plate.

2.1.8 Peak-pressure Gauges

Two types of gauges were used in taking measurements of peak pressure. One was a conventional pressure gauge from which the motor and initiation circuits were missing and in which the turntable was blocked to prevent movement. A round glass disk was used as the recording medium. The other was a smaller gauge designed for the specific purpose of taking peak measurements. This gauge had a baffle plate the size of those used on the pressure-time gauges, and the pressure capsule was mounted similarly. The recording medium was a $^1/_2$ by 1-in. aluminized glass rectangle glued to a movable block. The block was put in place under the capsule stylus, moved to produce a zero-deflection marker, and then locked in place by means of screws. In this way, peak positive and negative excursions of the capsule were registered. A heavy steel cup was bolted over the mechanism to maintain it at a constant pressure during passage of the blast wave (Fig. 2.7).

2.1.9 Peak-displacement Gauge

The peak-displacement gauge consisted of two parts: an aluminum rod welded to a circular aluminum base and a plate drilled to allow the rod to pass through freely. The plate had a spring-loaded knife edge attached, which scratched the moving rod. When installed, the rod assembly was attached to the moving member (Fig. 2.8), the drilled plate was slipped over the rod, and the plate was then attached to a stationary reference point. After the gauge was positioned, the rod was painted with black paint; thus, when the rod was activated by the blast, the knife edge scratched a record of the maximum position and negative deflection.

2.2 ELECTRONIC RECORDING GAUGES

2.2.1 Recording Mechanism

Each electronic recording system was, basically, a 20-channel phase-modulated-carrier magnetic-tape recorder. It was designed for use with gauges based on passive impedance elements, which modify a constant input voltage as a function of the physical activation being measured. A block diagram of the circuitry is shown in Fig. 2.9.

Each gauge contained, or was used in conjunction with, a full-reactance bridge that was balanced when no physical activation was applied to the gauge. In case such balance were not inherent in the gauge, provision was made in the coupling unit for simulating unequal react-

ances in adjacent arms of the bridge, whereby it could be balanced. The power supply produced an alternating input (E_i), having a crystal-controlled frequency of 3750 cycles/sec and a potential of 18 volts, which was fed to the balanced bridge in each gauge through its coupling unit. The phase of the voltage measured across the gauge was determined by a phase-shift network in the coupling unit and by the reactances in the gauge and its cable.

When physical activation was applied to the gauge, the bridge became unbalanced, and the output of the gauge changed from zero volts; its balance value changed to a small (hundredths of a volt) value (E_o). This voltage was closely proportional to the magnitude of the unbalance and was dependent on E_i.

The gauge output voltage (E_o) was fed through a 1-to-10 transformer into the gauge amplifier. In the first stage of this amplifier E_o was combined with a 3750 cycle/sec quadrature voltage (E_Q) and a fixed voltage (E_R), twice the frequency of E_Q and of fixed phase. These voltages were derived from the same supply as E_i and, in the event of any small amplitude or frequency fluctuation in E_i, were affected proportionally.

The quadrature voltage was so called because its phase differed from that of E_o by 90 deg. This phase shift was obtained by the combined effect of three phase-shift networks. The first of these, incorporated in the power supply, also determined the phase relation between E_Q and E_R. The second network was incorporated in the coupling unit and gave the additional phase shift necessary to obtain approximately the total 90-deg shift. The third network included in the amplifier provided a fine adjustment for setting exactly the 90-deg shift.

The voltage-vector diagram of Fig. 2.10 shows how E_o and E_Q combine to form a resultant voltage (E_r) having a phase angle (ϕ) with reference to E_Q. When E_o is a continuously varying voltage, ϕ is, then, a continuously varying function of E_o and

$$\phi = \arctan (E_o/E_Q)$$

The voltages E_r and E_R are then amplified 10 times and impressed on the recording head. These two voltages are simultaneously recorded by the same head on the same strip of tape. This process distinguishes the recording system for the voltage E_R, which is the reference on which interpretation of the recorded signal E_r depends, and is subject to precisely the same recording and playback variations as the signal itself. The variations mentioned are changes in spacing between recording head and tape, differences in thickness and sensitivity in adjacent regions of the tape, and weaving of tape and variations in speed as the tape is transported through the head. These variations seriously afflict amplitude-modulated and unreferenced or separately referenced phase systems.

2.2.2 Playback

The data recorded on the tape are in the form of a phase-modulated signal, which is not directly usable until it is passed through a phase discriminator and converted to an amplitude-modulated signal.

A block diagram of the entire playback unit is shown in Fig. 2.11. The playback uses the same head and transport mechanism used in recording, however, a different drive motor is used which pulls the tape through at half the recording speed. Thus the signal voltage (E_r) appears with a mean frequency of 1875 cycles/sec and the reference voltage (E_R) appears with a frequency of 3750 cycles/sec. These two voltage components are separated by band-pass filters, and the output of each filter is then differentiated to give a series of alternately positive and negative pulses having repetition and phases identical to those of input signals. The set of pulses corresponding to E_r is passed through a circuit that separates the positive pulses from the negative, inverts them, and recombines them to give a series of negative pulses having a mean repetition rate of 3750 cycles/sec and phase shifts proportional to those of E_r. The set of pulses corresponding to E_R is passed through a circuit that removes all positive phases and gives a series of negative pulses having a repetition rate of 3750 cycles/sec.

The pulses are amplified, clipped, and sharply differentiated in the pulse-generator circuits. The resulting spikes are fed into the two control grids of an Eccles-Jordan flip-flop circuit; the E_r spikes going to one grid and the E_R spikes going to the other. The constant-

phase E_R spikes turn the flip-flop "on" and the variable-phase E_r spikes turn it "off."* The resulting rectangular wave train is fed to a low-pass filter, which produces a voltage output proportional to the "on" time of the flip-flop. The 500 cycle/sec cutoff of the filter is sufficiently high to allow data containing frequency components up to 400 cycles to be passed without serious attenuation.

The output voltage, being directly proportional to ϕ, is proportional to the tangent of the magnitude of the physical activation measured. When ϕ is kept sufficiently small by proper choice of the voltage E_o

$$\tan \phi = \phi$$

and the operation is essentially linear; however, the system is always calibrated to provide added precision and to allow satisfactory treatment of over-load signals.

Minor additions to the system allow an accurate timing system to be included. The output of a standard EG&G Blue Box was fed directly to an auxiliary recording head, which put a sharp zero-time fiducial marker on the tape. During playback, the pulses formed from the reference voltage E_R were fed into a series of decimal divider circuits, which produced a set of pulses having a repetition rate of 375 pulses/sec.† Every tenth pulse was doubled in magnitude, and every hundredth pulse was tripled.

2.2.3 Electrical Calibration Steps

The calibration of the system was performed as much as two or three weeks before the actual test. To take into account any system-sensitivity differences that might have occurred in that time, provision was made for shunting a fixed resistor or inductance across one of the gauge bridge elements. This simulated an activation of the gauge, the magnitude of which was dependent on the size of the resistor or inductance. The simulated activation was produced just prior to calibration and again just prior to the test. If the simulated-activation amplitude was small enough to keep it within the linear range of the recorder, the signals produced in the playback were proportional to the system sensitivity at each time, and the proportionality factor indicated could be applied directly to the linearized record (see Sec. 2.6.2). These signals appeared on each finished oscillogram as "electrical cal steps."

2.2.4 Data Presentation

The final presentation of the data was obtained by applying the three signals (data, zero-time marker, and timing pulse) to three galvanometers in a photographic-paper graphic recorder.

2.2.5 System Details

The tape used was 35-mm-wide iron oxide - coated mylar. It was pulled during recording by a capstan drive at a speed of 28 in./sec. The heads were incorporated in two blocks of eleven each, displaced in relation to the tape so that a total of 22 record tracks was produced (interspaced) on the tape. Twenty of these tracks were used for recording data, and one (at the edge of the tape) was used to record the zero-time pulse; the remaining track was not used. Bias coils were provided in each head but were not used. The gauge amplifiers and the gauge coupling units were all separate, one of each being used for a channel. These were housed in racks on blocks of twenty each.

The drive motors operated from 28 volts direct current, which was supplied by storage batteries. The tube filaments and high-voltage-supply dynamotors operated from these batteries also.

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*The terms "on" and "off" were arbitrarily chosen to differentiate between the two stable states assumed by the flip-flop circuit.

†This corresponded to a repetition rate of 750 pulses/sec at recording speed.

The recorders have shown themselves to be reliable. Few failures have occurred, and the accelerations to which they were subjected during the passage of ground shock and blast waves have produced only small transient effects.

2.2.6 Blast Shelters

Recording equipment was housed in blast shelters (Figs. 2.12 and 2.13), partially or completely buried. The shelters were placed at a maximum of 1500 ft from the gauges, and, generally, at a distance from Ground Zero (GZ) greater than the corresponding distance from the gauges to prevent complete loss of records should the passing blast wave over the shelter cause failure of recorders. Standard 110-volt alternating current was supplied for operation of the recorders during the period of preparation prior to the test. This voltage supply was not relied on during the test; battery supplies were used in all cases.

2.2.7 Initiation

Initiation and control of the recorder operation was by means of timing signals supplied by EG&G Project 9.2.

The EG&G installation consisted of the proper timing lines run into the shelter and five relays, one being provided to close at each of the following times: minus 30 min (i.e., 30 min before the instant of detonation), minus 15 min, minus 15 sec, minus 5 sec, and minus 1 sec. EG&G guaranteed the closure of each relay. Since EG&G gave no promise that the relays would remain closed, however, they were connected to operate latching relays in a sequence-timer unit. The closure of the latching relays then activated the recording equipment.

The signal that closed the minus 30-min relay actuated the latching relay, connecting the 28-volt battery to the amplifier filaments and to the high-voltage power supplies. So that there would be no loss of records in case of failure or ineffectuality of this signal, closure of the minus 15-min relay applied excitation to another latching relay, which duplicated the operation of the first.

Two more operations were necessary, and the three remaining relays were provided to ensure their being performed. Normally, the first operation was effected by the minus 15-sec closure. This operation consisted in activating the electrical cal step relays and the tape drive motors. The minus 5-sec closure had, as its prime purpose, the initiation of a 2.5-sec time delay but was also capable of performing the function of the minus 15-sec closure if the latter should fail. The 2.5-sec delay relay removed the electrical cal step and started an auxiliary timer. The minus 1-sec signal duplicated the operation of the time-delay relay.

After 2 min, the auxiliary timer applied and removed a postshot electrical cal step, stopped the tape, and removed power from the system.

2.3 TRANSDUCERS

2.3.1 Self-recording Pressure Element

Two views of the self-recording pressure element used in the pressure-time and dynamic-pressure gauges are shown in Fig. 2.14. Basically, this element is a chamber formed by the welding together at their edges of two diaphragms, each of which is impressed with a series of concentric corrugations. Pressure is transmitted to the inside of the element through an inlet port, which passes through a heavy brass mounting flange. In operation, the element is mounted on the inside of the gauge baffle plate with the inlet port of the element lining up with the pressure hole in the baffle plate. Thus the blast pressures are transmitted to the inside of the element while the outside is held at the constant pressure sealed inside the gauge casing (Sec. 2.1.1). This causes the element to bulge and move the stylus out from the element mount a distance proportional to the pressure.

Without the concentric corrugations, elements of this type display severe nonlinearity of deflection vs. pressure. In a corrugated element, however, each of the sections bounded by one of the corrugations is sensitive to essentially one small range of pressures and responds linearly over that range. Over the total range of the element, which is the sum of the ranges of all the sections, the response is, then, practically linear. The actual value of linearity is ±0.5 per cent.

A minimum element volume, with a corresponding short fill time is ensured by designing the corrugations of the two diaphragms forming the chamber to nest with one another. The volumes achieved require a fill time not exceeding 3 msec.

By careful choice of diaphragm material (Ni Span C stainless steel was used) hysteresis was kept down to ±0.1 per cent, and elements could be operated linearly and without damage up to pressures 150 per cent of the rated ranges. Depending on the pressure range, the elements had undamped natural frequencies of 250 to 2000 cycles/sec.

Careful control of metal qualities and manufacturing processes ensured that the path traced by the stylus, as the element expanded, was within 1 deg of being a perfectly straight line normal to the mount surface. The allowable discrepancy produced a stylus motion in the direction of the time axis of the disk corresponding to $\pm\frac{1}{2}$ msec at a disk speed of 10 rpm. This error would not be found in arrival-time measurements but represents the time error that might be found in determining the occurrence of a peak.

The stylus was an osmium phonograph needle tip mounted on a phosphor-bronze spring arm. Stylus pressure was adjusted by bending this arm until a small auxiliary spring scale indicated proper tension. No special attempts were made to damp the motion of the capsules for use in the pressure-time gauges since, with the dust screen used, damping was adequate for any capsule range and overshoot was never objectionable.

The total-pressure capsule, used at the end of the long tube in the nose of the dynamic-pressure gauge, was more susceptible to overshoot and was effectively damped to 0.7 of critical. This was accomplished by changing the fill time with a sieve. Its head was placed directly over the capsule inlet port. The sieve was made by drilling sixteen No. 80 holes in a piece of brass shim stock.

2.3.2 Electronic Displacement Transducer

The displacement gauge was mounted on a stable surface; it measured the relative movement of an object by means of a hardened-steel wire connected from the gauge to the object.

This wire was wrapped around a pulley mounted on a shaft supported by journals in the ends of the gauge case. A heavy coil spring inside the case applied torsion to the pulley shaft so that the wire was held in tension and would wind on or off the pulley as the object moved. A ratchet on the pulley shaft allowed the spring to be wound to, and held at, a high value of torque prior to installation of the wire. Release of the ratchet applied tension to the wire.

The free end of the pulley shaft was attached to the recording mechanism. The gauge sensitivity was determined by the pulley size, smaller pulleys being used with smaller displacement. The tension in the wire was about 60 lb, and the gauge was able to follow a displacement rate of 25 ft sec. Two standard electronic transducers were used (Figs. 2.15 and 2.16), depending on the magnitude of the displacement. Both types were the ratchet-wound spring-loaded pulley assembly described above. The large-displacement model (1 to 18 in.) produced the required modulation of the carrier voltage by means of a continuous-rotation wire-wound potentiometer attached to the pulley shaft. The housing of this potentiometer, rather than being permanently fixed to the gauge casing, could be rotated by a knob with a calibrated scale. Rotation of this knob in a direction opposite to the expected rotation of the displacement gauge pulley allowed pulley rotation to be exactly simulated, and, by means of the calibrated scale, the magnitude of a corresponding displacement could be determined. This procedure was followed in the calibration of the recording channels used with this gauge. The potentiometer was then locked in place.

The small-displacement model (0 to 1 in.) used a linearly variable differential transformer (LVDT) as a variable-impedance element. The coil of the LVDT was composed of three windings; the middle winding was the input (or primary) winding that was connected to the gauge power supply. The motion of the armature differentially varied the coupling between this winding and windings on either side of it. The outside pair of windings was connected in series with the recorder so that the output voltages opposed one another. When the armature was centered between them, the net voltage output applied to the recorder was zero. As the armature was displaced from its balance point, an output voltage proportional to the motion was produced. The hollow cylindrical armature of this transformer was threaded over the gauge wire and clamped in place, and the solenoid winding of the transformer (inside which the armature moved axially)

was held by a rigid frame. Thus the gauge sensed directly the axial motion caused by the displacement, and the pulley arrangement served only to produce tension in the wire.

The coil was not permanently fixed to its support; but, to simulate a motion of the armature, the coil could be moved with respect to the stationary armature. This movement was measured by a dial micrometer to effect a calibration (see Sec. 2.5.4). After calibration, the coil was locked into position.

These gauges could follow a displacement rate of 25 ft/sec.

Three special-application displacement gauges were also designed. One measured the bending of the sliding blast-door used on the Project 30.2 dual-purpose parking garage–mass shelter (Fig. 2.17). A hardened-steel wire was stretched from one edge of the door, over a 12-in.-long perpendicular stud at the center of the door, and attached by a strong spring to the other edge of the door. A hollow cylindrical armature for an LVDT was threaded on the wire and clamped close to the spring. As the door bowed in, the stud forced the wire to stretch the spring; consequently, the position of the armature changed relative to the edge of the door. The LVDT coil was mounted close to the edge of the door and sensed the motion of the armature.

Also, an LVDT coil was mounted on the garage floor with its axis perpendicular to the sliding door (Fig. 2.18). The armature was forced into the coil against spring tension and held there by the door. Thus any linear motion of the door relative to the floor was followed by the armature.

Finally, LVDT's modified by the manufacturer (Schaevitz Engineering Corporation) to have an extended range (5 in.) were used to record the operation of blast valves tested by Project 31.5 (Fig. 2.19). The armatures were attached directly to the moving part of the valve; whereas the coil was held fixed with respect to the valve seat. Thus the entire cycle of the poppet could be followed.

2.3.3 Pressure Transducers

Measurements of blast pressure were made with Wiancko 3PAD-R pressure gauges (Fig. 2.20). Each gauge was contained in a heavy brass casing, which minimized transient temperature effects. A threaded flange around the sensitive end of the casing allowed the gauge to be screwed into its mount. A plug in the other end of the casing provided a signal-cable connection. The gauge was a variable-differential-inductance type using a twisted Bourdon tube sensing element. One end of the tube was open to the atmosphere, and the other end was closed and attached to an armature held in close proximity to an E coil (Fig. 2.21). As pressure was applied to the open end, it tended to straighten the twisted tube and, in so doing, rotated the armature.

The E coil consisted of two windings wound on the extreme legs of an E-shaped magnetic core. As the armature rotated, it decreased the reluctance of the magnetic path composed of the armature, the center leg, and one extreme leg of the E and increased the reluctance of the other, similar path.

With the two windings connected into a full-impedance bridge, a voltage unbalance was created which was proportional to the applied pressure.

The response time of this type gauge varied with its range, but it was, in all cases, smaller than the response time of the recording system (about 2 msec).

Wherever these gauges were used close to, and facing, the blast, shields of aluminum foil were used to prevent thermal radiation entering the pressure port and distorting the Bourdon tube.

2.3.4 Electronic Dynamic-pressure Gauge

The dynamic-pressure gauge used was one designed by Sandia Corporation (Fig. 2.22). It employed two Wiancko pressure elements (as described in Sec. 2.3.3, without the brass casing) installed in a Pitot tube. One element measured the difference between the total and the side-on pressure, and the other element measured only side-on pressure. Consequently, the gauge produced two signals (recorded on separate channels), the first being a function of dynamic pressure and the second being a function of side-on pressure.

2.3.5 Accelerometers

Acceleration measurements were made with Wiancko type 3 AAT accelerometers (Fig. 2.23). The sensing element consisted of an armature bonded at its center to the vertex of a V-shaped spring member and held in close proximity to an E coil of the type described in Sec. 2.3.3 (Fig. 2.24). A weight, the mass of which depended upon the range of the accelerometer, was attached to one end of the armature so that an acceleration in a direction normal to the armature caused it to rotate about the vertex of the spring. The rotation of the armature caused unbalance in a full-impedance bridge, of which the windings of the E coil were a part.

The accelerometer was, incidentally, sensitive to rotational accelerations; so it could not be used where these were present. The stiffness of the spring was such that linear accelerations in the direction of the axis of the case only were measured.

The natural frequency of a 5-g accelerometer was approximately 70 cycles/sec, and of a 100-g accelerometer, approximately 450 cycles/sec. The gauges were damped to 0.70 of critical at a temperature of 80°F.

2.3.6 Earth-pressure Gauges

The earth-pressure measurements were made with a Wiancko-Carlson type 3-PE footing-stress gauge (Figs. 2.25 and 2.26). The sensing mechanism consisted of two inflexible circular plates with thinned edges, separated and welded around the periphery so that the edges acted as a flexible section. The small chamber volume between the plate inner surfaces could be varied by pressure on the external surfaces. The chamber was filled with fluid, usually mercury or oil. The center section of one plate was thinned to form a diaphragm which bulged outward when externally applied pressure squeezed the two plates together. This motion was coupled to an armature (Fig. 2.26), causing it to move near an E coil (described in Sec. 2.3.3). The diaphragm plate was the base for the gauge and was placed against the footing. As pressure was applied, the motions of the solid plate and the flexible diaphragm were in the same direction, but the amplitudes of their motions were in inverse proportion to their respective areas. The resulting amplification of motion permitted relatively large gauge output, while maintaining high-frequency response.

2.4 GAUGE MOUNTS

2.4.1 Self-recording Pressure Gauges

Several methods were used to mount the pressure-time gauges. The requirements for Project 30.1 and part of Project 31.4 were for gauges to measure diffraction patterns of the blast wave; in these cases it was necessary to mount the gauge baffle plate flush with the surrounding surface. This was done by casting the gauge casings into the concrete during construction of the test objects; later, the gauge mechanisms mounted on the baffle plates were inserted into their casings, and the baffle plates were bolted in place (Figs. 2.27 and 2.28). In all other cases, where the gauges were used to indicate the fill time and maximum pressures inside a structure, a nipple welded to the bottom of the gauge casing was screwed onto a threaded length of 3-in. pipe cast into the concrete of the structure (Fig. 2.29) or attached to a 12-in. steel disk held in place by sand bags.

2.4.2 Self-recording Dynamic-pressure Gauges

The dynamic-pressure gauges were provided with two short nipples (see Sec. 2.1.7) for mounting in low-pressure regions. Mounts were constructed using a pair of parallel lengths of 3-in. pipe braced and held at a constant spacing by short lengths of steel plate welded between them (Fig. 2.30). Two lengths were used, 5 ft for gauges to be mounted 3 ft above the surface and 12 ft for gauges to be mounted 10 ft above the surface. The pipes were embedded in concrete at the base and steadied by guy wires, where needed. Pipe unions were used to attach the gauge nipples to the mount pipes. For the high-pressure regions, a much heavier mount was used (the standard AFSWP gauge tower design) in conjunction with a special casing that butted up to a flange provided on the front surface of the mount (Fig. 2.31).

2.4.3 Electronic Deflection Gauges

The standard electronic deflection gauges were mounted with four properly spaced $\frac{1}{4}$-in. bolts, cast or ram-set into the stable mounting surface. The gauge, with four corresponding bolt holes, was set over them and secured with nuts (see Fig. 2.32).

The mounting details of the two special deflection gauges are given in the description of the gauges in Sec. 2.3.2.

2.4.4 Peak-pressure Gauges

These gauges, using standard self-recording pressure-gauge cases, were mounted as described in Sec. 2.4.1.

The specially designed peak-pressure gauges were mounted with the face of the baffle plate toward the mounting surface. Studs were driven into the surface. Properly spaced holes in the baffle plate allowed it to be slipped over the studs and secured in place. Spacers were placed on the studs to hold the pressure port away from the surface.

2.4.5 Electronic Pressure Gauges

The electronic pressure gauges were used in the concrete structures.

Seamless steel tubs, threaded to accept the gauge casings, were cast into the concrete structures (Fig. 2.33).

2.4.6 Electronic Dynamic-pressure Gauges

Standard heavy AFSWP vertical pipe mounts were provided for these gauges (Fig. 2.34). The mount consisted of a pair of 8-in. pipes spaced by tangential steel plates welded between them. A flange facing GZ was provided and to this was bolted a section tapered to the diameter of the Pitot tube. The Pitot tube was inserted in this section and locked into position by set screws.

2.4.7 Accelerometers

The accelerometers were mounted on the member in which the acceleration was being measured. A lead plate $\frac{3}{16}$ in. thick and the diameter of the gauge was installed between the gauge and member to eliminate gauge ringing effects. Three properly spaced threaded studs were cast or ram-set into the concrete. The gauge was positioned so that three holes drilled in a flange around one end of the gauge case were fitted over the studs. Thus the gauge was mounted with its sensitive axis (the axis of the cylindrical case) lying parallel to the direction of the acceleration being measured.

2.4.8 Earth-pressure Gauges

Depending on the application, different methods of mounting the earth-pressure gauges were employed. In every case, provision was made for allowing a solid, flat surface for support of the gauge base plate and an even distribution of pressure over the sensitive plate (see Sec. 2.3.6).

In the case of the Project 30.2 garage, cavities matching the contours of an earth-pressure gauge were cast in the concrete. The gauges were then grouted into position and, as the structure was backfilled, sieved sand was carefully packed over each gauge face to ensure a uniform pressure distribution.

2.5 CALIBRATION

2.5.1 Self-recording Pressure Gauges

Calibration of the pressure capsules was performed by the manufacturer. The calibrations were plotted with a Leeds-Northrop X-Y recorder. The output of a Statham Instruments, Inc., strain-gauge pressure transducer was fed through amplifiers to the pen (X-axis) of the recorder. Capsule deflection was measured by a micrometer head equipped with a null detec-

ter and a servo system operating a slide-wire potentiometer which, in turn, controlled the chart drive (or X-axis). The resulting presentation gave a plot of capsule deflection as a function of applied pressure (see Fig. 2.35).

The disk drive motors were also individually tested for start-up time and speed. The speed was tested by comparing the frequency of the pulses produced by the governor contacts with pulses from a precision-signal generator.

The start-up time was deduced from a plot of angular displacement of the motor shaft vs. time (Fig. 2.36). The curve was obtained by attaching the shaft of a potentiometer (Helipot) having 0.05 per cent linearity to the center of the gauge turntable. The potentiometer, which was powered by a battery, produced an output that was registered by a moving-paper oscillograph. The oscillograph provided a time base, and the potentiometer output was proportional to the angle through which the shaft had turned. Another channel of the oscillograph recorded a fiducial marker at the instant voltage was applied to the motor.

The slope of the recorded curve thus indicated velocity, the constant terminal velocity being indicated by that portion of the curve having a constant slope. The times of occurrence of all variations from this constant velocity were also clearly indicated. Finally, when the constant-slope portion of the curve was extended through the time axis, its intersection gave a starting delay time to be added to event times computed on the basis of an instantaneously achieved constant motor speed.

2.5.2 Self-recording Dynamic-pressure Gauges

The procedure given in Sec. 2.5.1 was used in calibrating the self-recording dynamic-pressure gauges.

2.5.3 Peak-pressure Gauges

These gauges used the same elements as those used in the self-recording pressure gauges, and calibration procedures were the same (see Sec. 2.5.1).

2.5.4 Electronic Displacement Gauges

Calibration of the gauges was necessarily performed after installation of gauges and recording system. For all gauge types, this was done by moving the normally stationary element of transducer relative to its normally movable element.

The normally stationary element of the large-displacement gauge was the potentiometer housing. This housing could be rotated by a linearly calibrated knob (see Sec. 2.3.2), a full-scale rotation from its centered position corresponding to a half turn in the opposite direction by the gauge pulley. The corresponding displacement was equal to one-half the pulley circumference. The full range of the calibrated scale was divided into five equal segments on each side of its centered position; thus positive and negative displacements of 20, 40, 60, 80, and 100 per cent of the maximum calibration value could be obtained. Where displacements greater than one-half the pulley circumference were obtained, the potentiometer rotated past the extreme point on its scale and began a second cycle. The calibration for this cycle was identical to that for the first cycle, except that a displacement equal to the pulley circumference was added to (or subtracted from) the indicated displacement value. Whether the constant value was to be added or subtracted was dependent on the slopes of the curve of displacement vs. time just prior to the sharp discontinuity marking the beginning of a new cycle. Positive slopes indicated addition; negative slopes indicated subtraction.

The small-displacement gauges were calibrated with a dial micrometer as a standard. The micrometer measured the motion of the coil relative to its support or armature position. After the clamp that held the linear variable differential transformer coil in place was loosened, a slotted block, which held the micrometer, was slipped over the coil support bar (see Fig. 2.37) and locked in position. The coil was moved until its electrical center (the position giving an output voltage null) was found. The reading indicated by the micrometer was then taken as the zero reading, and from this point the coil was moved in a direction opposite to the actual displacement to produce calibration steps. Values, both positive and negative, of 20, 40, 60, 80, 100, 120, 140, and 160 per cent of the expected maximum were used.

2.5.5 Electronic Pressure Gauges

Steady pressure controlled by a system of regulators was applied to the Bourdon tube through a tube fitting screwed into the pressure inlet port (see Fig. 2.38). The regulators were contained behind a control panel, which also mounted dial gauges having ranges adequate to indicate all required pressures with an accuracy of ±2 per cent. The steady pressures were applied after installation of the gauges and recording system, with positive pressures 20, 40, 60, 80, 100, and 150 per cent of the expected maximum being applied. Where required, negative pressures in the same elements were also applied.

2.5.6 Electronic Dynamic-pressure Gauges

The calibration procedure for these gauges was identical with that described in Sec. 2.5.5. Negative calibrations were made for the side-on but not for the dynamic-pressure elements.

2.5.7 Accelerometers

The accelerometers were given static calibrations on a spin-table accelerator before their installation (see Fig. 2.39). The spin table was a disk that was rotated at a speed determined accurately by an electric tachometer. The accelerometer was mounted on the disk with its sensitive direction parallel to the radius of the disk. Connections to the recorder cable were made through slip rings. An accurate knowledge of the distance of the accelerometer sensing element from the center of the disk and the rotational velocity of the disk were used to find the radial acceleration produced in the sensing element. The disk velocity was varied to produce accelerations 20, 40, 60, 80, 100, and 150 per cent of the expected maximum. Spin-table acceleration values could be computed with an accuracy of 2 per cent.

2.5.8 Earth-pressure Gauges

These gauges were generally calibrated in pairs or groups of four before being placed in their mounts (see Fig. 2.40). Two gauges were placed with their sensitive faces together, but separated by a layer of blotting paper. An aluminum ring, slotted to allow exit of the gauge cable, was placed against each base plate to protect the protruding section of the gauge containing the sensing element (see Sec. 2.3.6). This sandwich was then placed, with a Baldwin SR-4 load cell, between the jaws of a hydraulic press. The force applied through the aluminum rings to the base plates was measured by the load cell to an accuracy of better than 1 per cent. The blotting paper allowed an even distribution of load over the sensitive faces of the gauges. Where convenient, several such sandwiches could be calibrated simultaneously.

2.6 DATA PRESENTATION

2.6.1 Self-recording Gauges

The data obtained from each self-recording record contain the arrival time and deflection vs. time. The records, being scribed on rotating glass disks, are presented in polar coordinate form. Conversion to rectilinear coordinates simplifies working with the data. To do this, a Gaertner toolmakers microscope with a rotating table was utilized. The microscope was modified by the addition of digital readout heads giving 1000 counts per revolution of the reading head shaft. Record deflection is represented by 0.000025 in. per count or 40 counts per mil of deflection. For the time-base readings, one revolution of the turntable (360 deg) will read 45,000 counts or 125 counts per degree.

The data from the readout heads of the microscope are converted to digital form and punched on IBM cards by Telecordex equipment. These cards are utilized in final processing.

2.6.2 Electronic Gauges

The playback of the magnetic-tape recordings produced by the electronic gauges were presented as oscillograms on strips of 7-in.-wide photographic paper. The data from each channel were presented on a single oscillogram. The information included: (1) electrical cal

step, made immediately prior to calibration (Sec. 2.2.3); (2) calibration steps, each made by running the recorder for a short period while the transducer was statically activated (Sec. 2.5); (3) electrical cal step, made immediately prior to detonation (Sec. 2.2.7); (4) the trace deflection caused by the physical activation; (5) electrical cal step, made shortly following the completion of the records; (6) zero-time marker (Sec. 2.2.2); and (7) a series of timing pulses produced at the bottom of the paper (Sec. 2.2.2). The relative heights of the electrical cal step H_c taken during the calibration run and H_t taken during the actual test run were proportional to the values of system gain during those times.

The calibration steps multiplied by the ratio, H_t/H_c determined the spacing of the ordinates of the plot; whereas the timing pulses determined the abscissas. Each minor timing pulse represented $1\frac{1}{3}$ msec; the larger spikes corresponded to $13\frac{1}{3}$ msec and $133\frac{1}{3}$ msec.

The oscillograms were read on a Telereader, which uses magnetic reading heads to convert the time, calibration, and record displacements to a digital form. The information in digital form is punched on IBM cards, which are used as input data for the EDVAC for final processing.

2.6.3 Final Data Presentation

The IBM cards, representing readings taken at close intervals throughout the span of the records, together with cards representing calibration readings and, in the case of the self-recording data, time-interval information, are used as input data for the EDVAC high-speed digital computer. The program as coded for the EDVAC uses a straight-line equation. The deflection values are calculated from a straight-line interpolation between the various calibration steps. The timing calibration is applied to the readings and concurrently the impulse is summed as the cards are processed. The final output of the EDVAC is time (msec) and deflection, linearized and punched on IBM cards. These cards are fed to an Electronic Associates, Inc., Variplotter, model 3033B1LP. This line plotter can plot and connect 66 points per inch with an accuracy of $\frac{1}{64}$ in. The final plots are from this plotter. Photographs of original records and linearized record plots with sketches showing their locations are included in Appendix B.

2.7 INSTRUMENTATION REQUIREMENTS

All requirements for instrumentation were established by FCDA Projects 30.1, 30.2, 30.3, 31.4, and 31.5. After the basic instrumentation type (electronic or self-recording) had been specified, the choice of recorders, transducers, and transducer mounts was the responsibility of BRL.

In cases where diffraction and loading studies were being made, electronic instrumentation was preferred to self-recording equipment because the latter had no provision for marking zero time.

A listing of structures, channels, types of measurements, and ranges is given in Table 2.1.

2.8 FIELD LAYOUT

Figure 2.41 shows the locations of structures instrumented, blast shelters, and ditching.

TABLE 2.1 — STRUCTURES AND INSTRUMENTATION

Project/Structure	Gauge type	No. of gauges	Ranges
30.1/8001.01	Accelerometer	4	73, 40, and 7.54 g
	Pressure	5	460, 250, and 70 psi
30.1/8001.02	Accelerometer	4	40, 20, 4, and 2 g
	Pressure	5	235, 180, and 35 psi
30.1/8001.03	Pressure	7	150, 100, and 20 psi
30.1/8008.00	Peak pressure	1	5 psi
30.2/8002.00	Pressure	5	300, 100, and 40 psi
	Earth pressure	11	200, 50, 25, and 15 psi
	Deflection	18	0 to 6 in.
	Dynamic pressure	1	200 and 40 psi (2 channels)
	Self-recording pressure	2	50 and 5 psi
	Self-recording dynamic pressure	1	200 and 50 psi (2 channels)
30.3/8003.01	Self-recording pressure	1	100 psi
	Peak pressure	1	15 psi
30.3/8003.02	Self-recording pressure	1	50 psi
	Peak pressure	1	5 psi
30.3/8003.03	Self-recording pressure	1	50 psi
	Peak pressure	1	5 psi
	Deflection	2	0 to 1 in.
30.4/8006.01	Self-recording pressure	3	15 psi
	Peak pressure	1	5 psi
	Peak deflection	5	0 to 5 in.
	Deflection	1	0 to 0.75 in.
31.4/8006.03	Self-recording pressure	3	15 and 5 psi
	Peak deflection	5	0 to 5 in.
31.5/8007.01	Deflection	1	0 to 5 in.
	Self-recording pressure	2	100 and 25 psi
31.5/8007.02	Deflection	1	0 to 5 in.
	Self-recording pressure	2	50 and 15 psi
31.5/8007.03	Deflection	1	0 to 5 in.
	Self-recording pressure	2	50 and 15 psi
31.5/8007.04	Deflection	1	0 to 5 in.
	Self-recording pressure	2	15 and 5 psi
31.5/8007.05	Deflection	1	0 to 5 in.
	Self-recording pressure	2	15 and 5 psi
31.5/8007.06	Deflection	1	0 to 5 in.
	Self-recording pressure	2	15 and 5 psi
31.5/8007.07	Deflection	3	0 to 5 in.
	Self-recording pressure	7	15 and 5 psi
31.5/8007.08	Deflection	2	0 to 5 in.
	Self-recording pressure	5	15 and 5 psi

Fig. 2.1—Pressure-time gauge enclosed in casing.

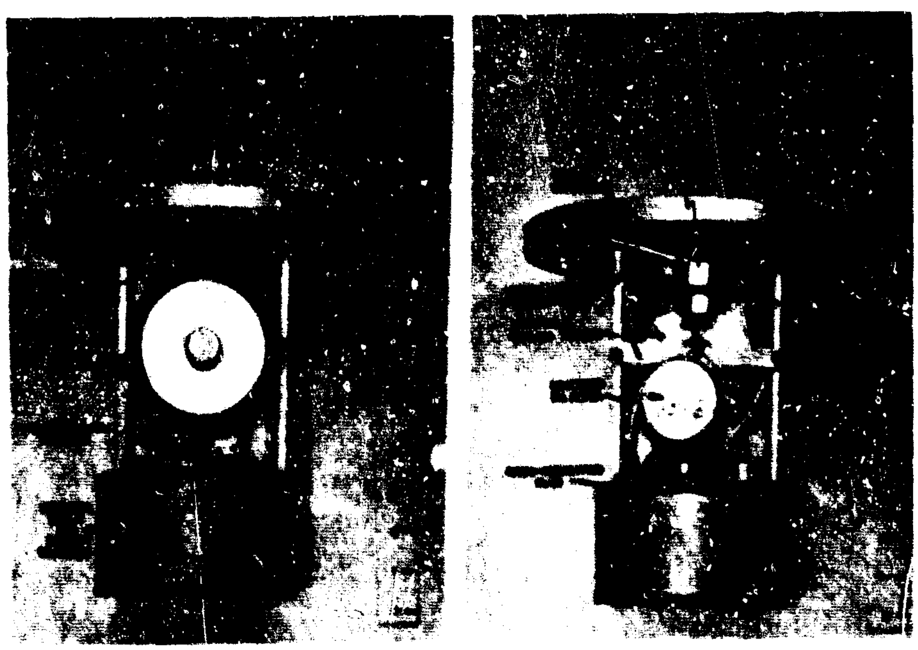


Fig. 2.2—Pressure-time gauge recording mechanism.

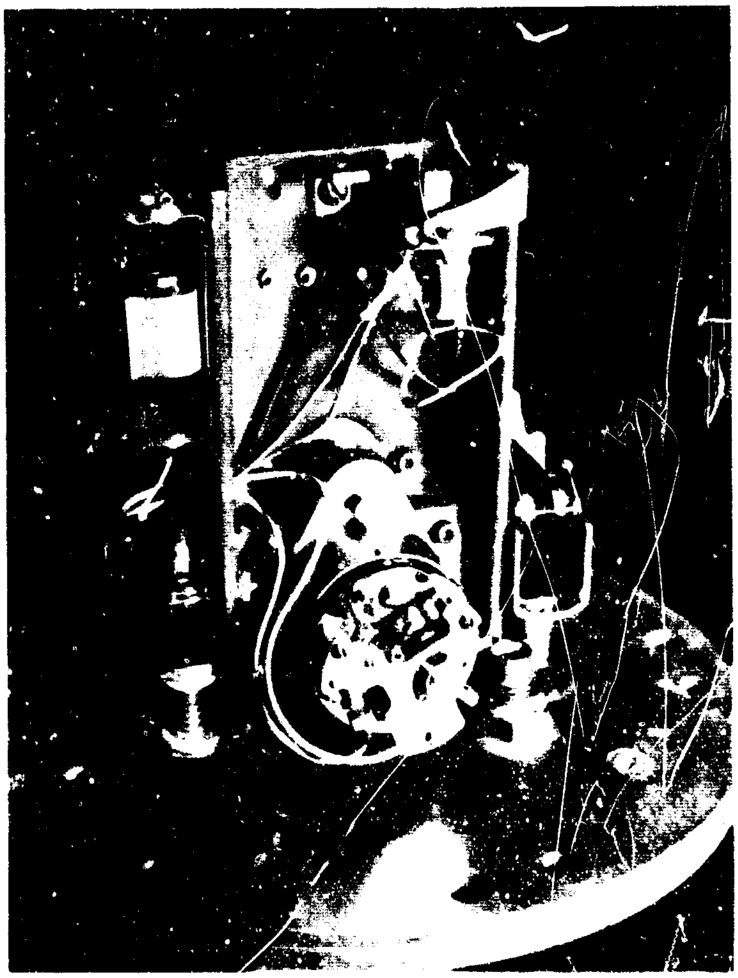


Fig. 2.3—Disk drive motor for self-recording gauge.

Fig. 2.4—Fully assembled dynamic-pressure gauge.

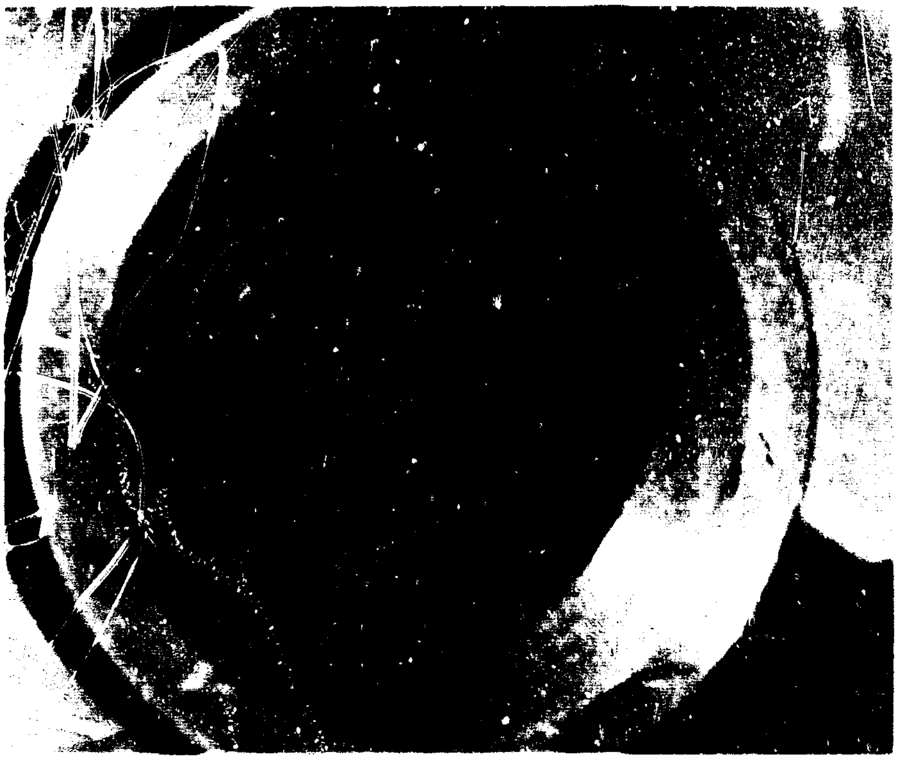


Fig. 2.5—Hollowed-out portion of dynamic-pressure gauge nose section

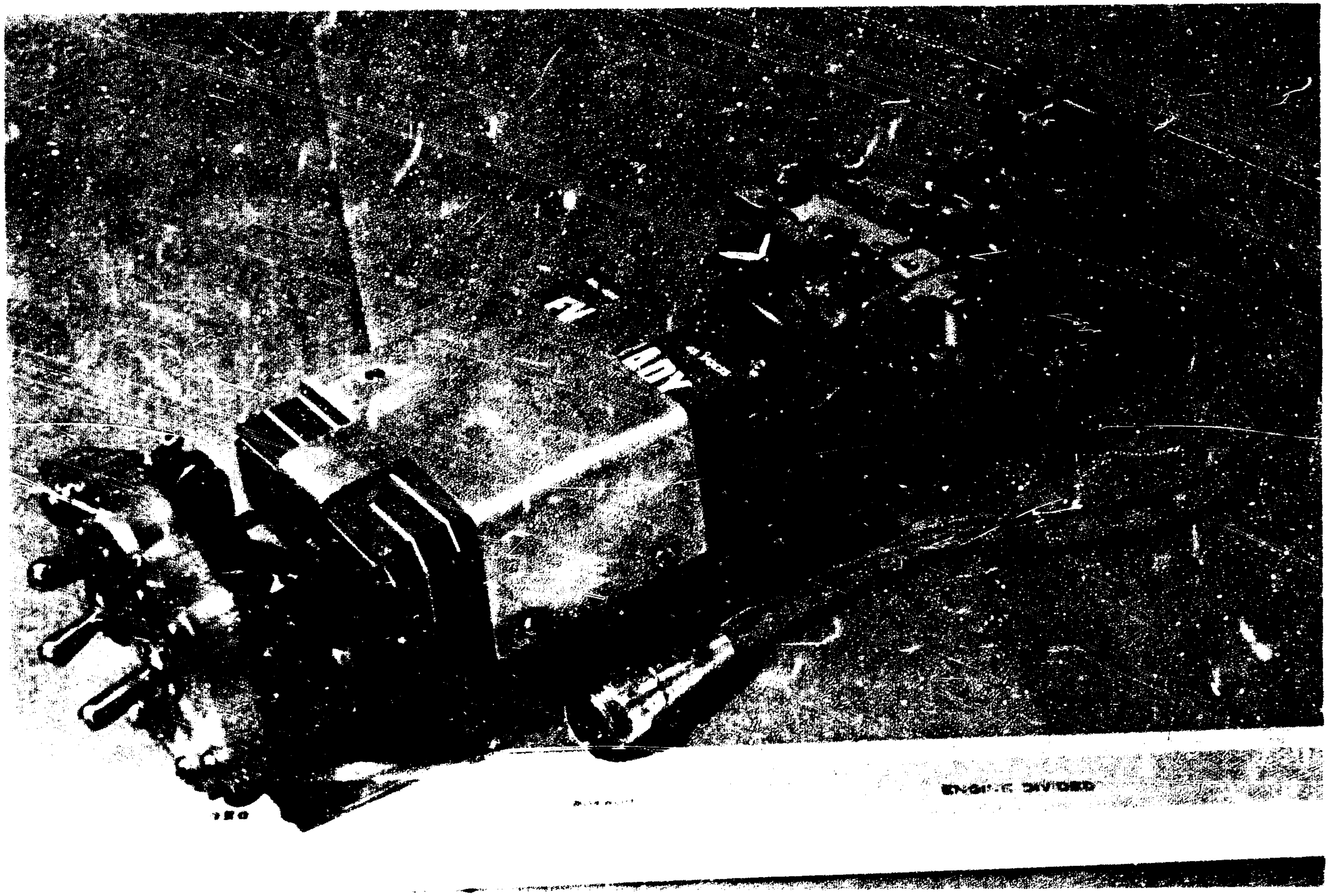


Fig. 2.6—Dynamic-pressure gauge power supply and initiator chassis.

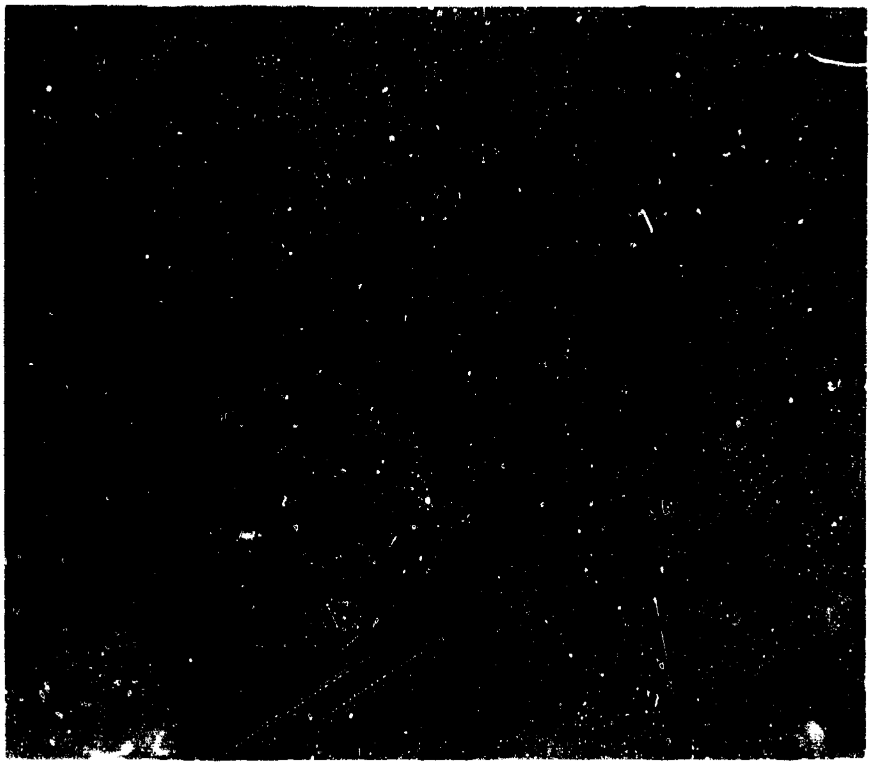


Fig. 2.7—Peak-pressure gauge.

Fig. 2.8—Peak-displacement gauge.

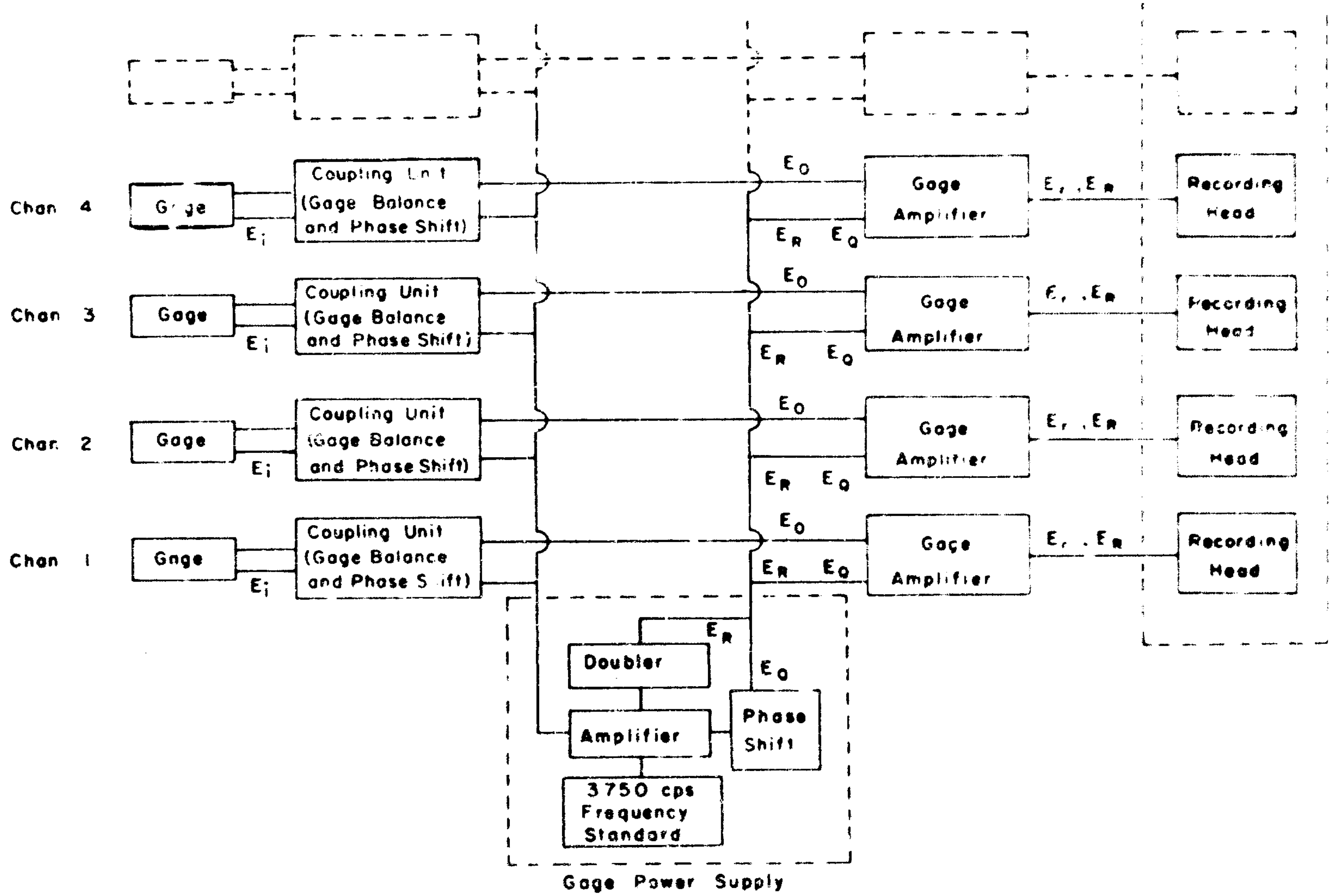


Fig. 2.9—Referenced phase-modulated recorder circuitry.

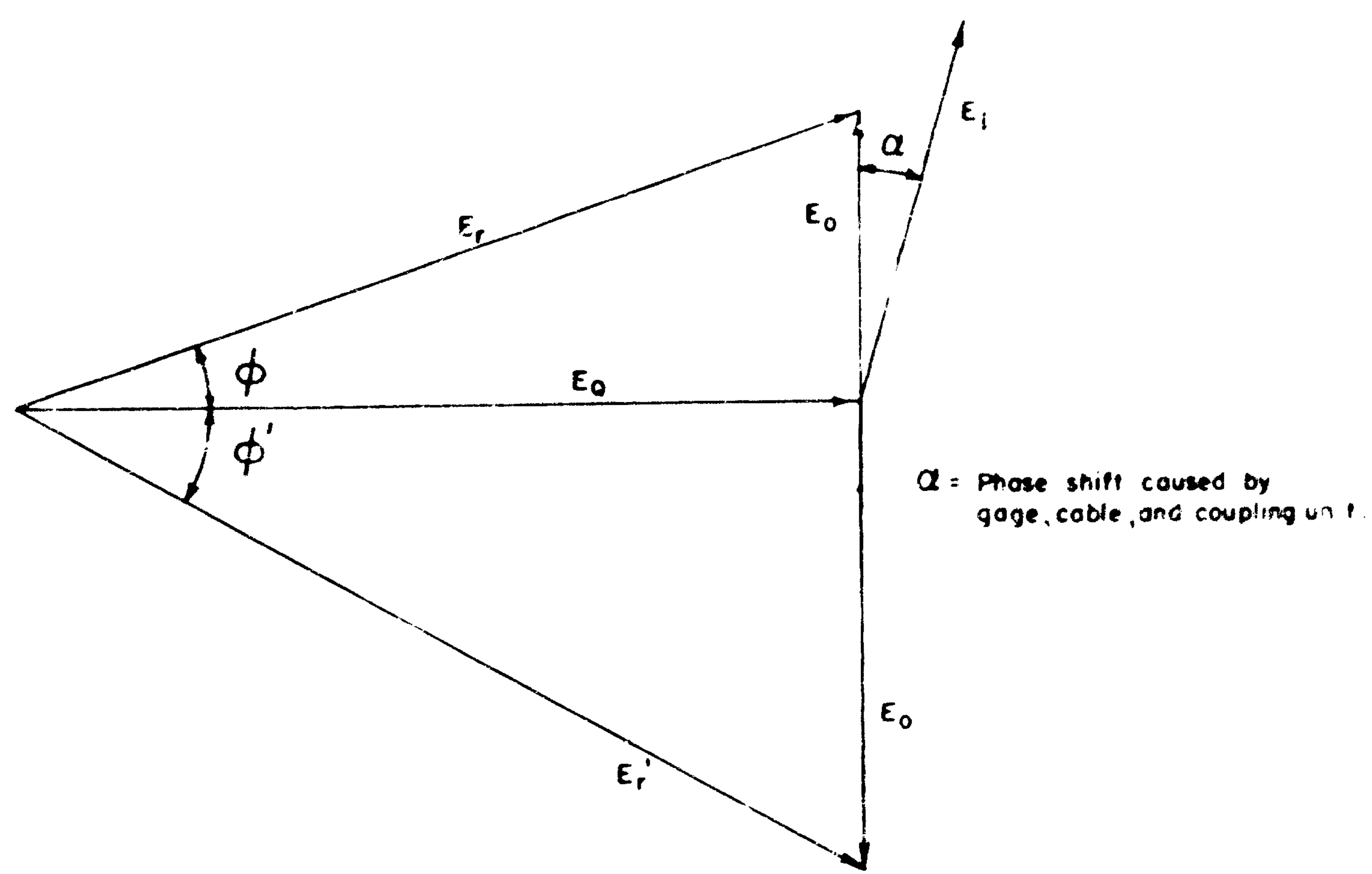


Fig. 2.10--Voltage relations in referenced phase-modulated recorder.

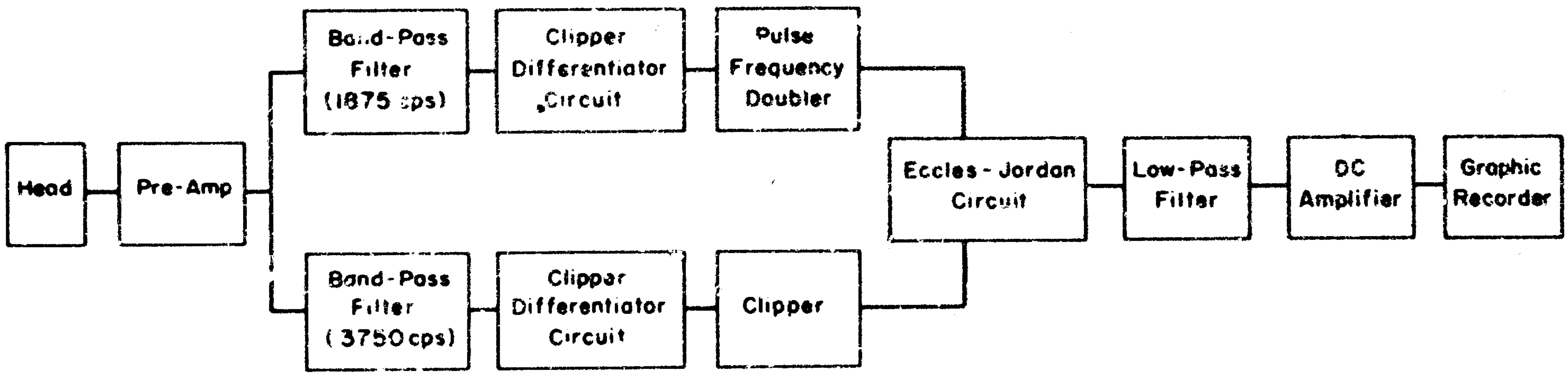


Fig. 2.11—Circuitry of playback unit for referenced phase-modulated records.

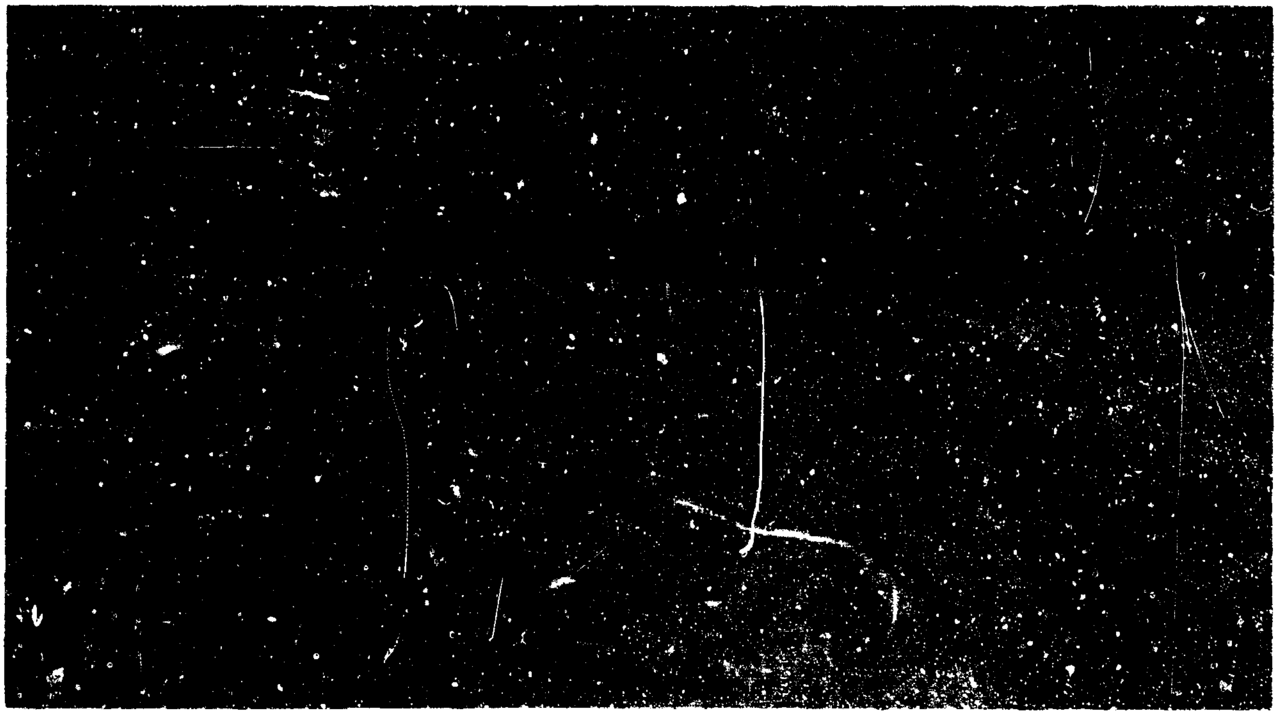


Fig. 2.12—External view of blast shelter.

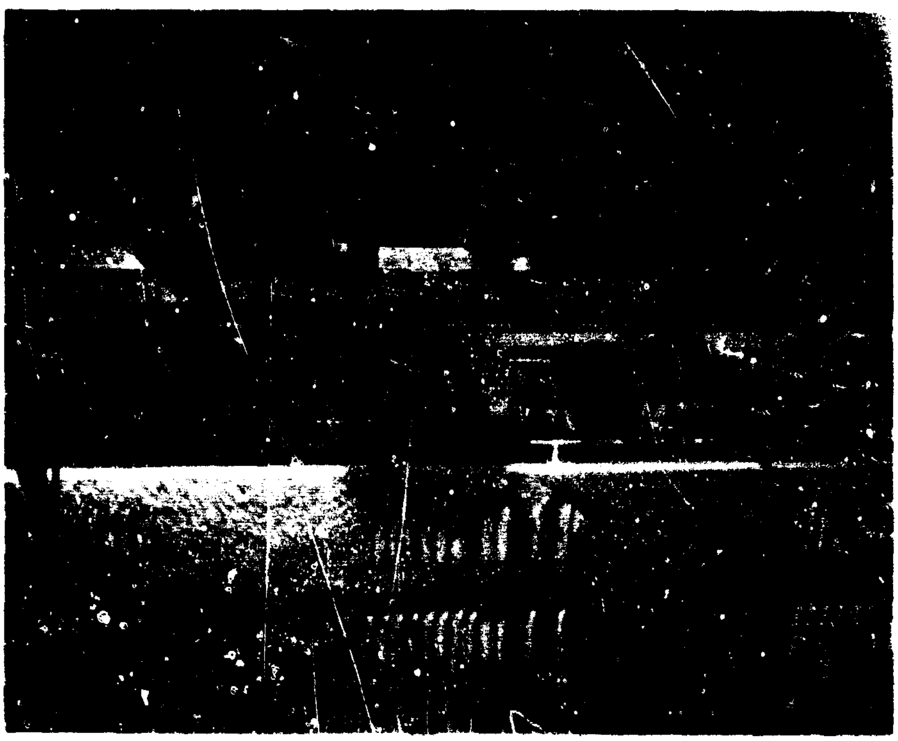


Fig. 2.13—Recording equipment installed in shelter.

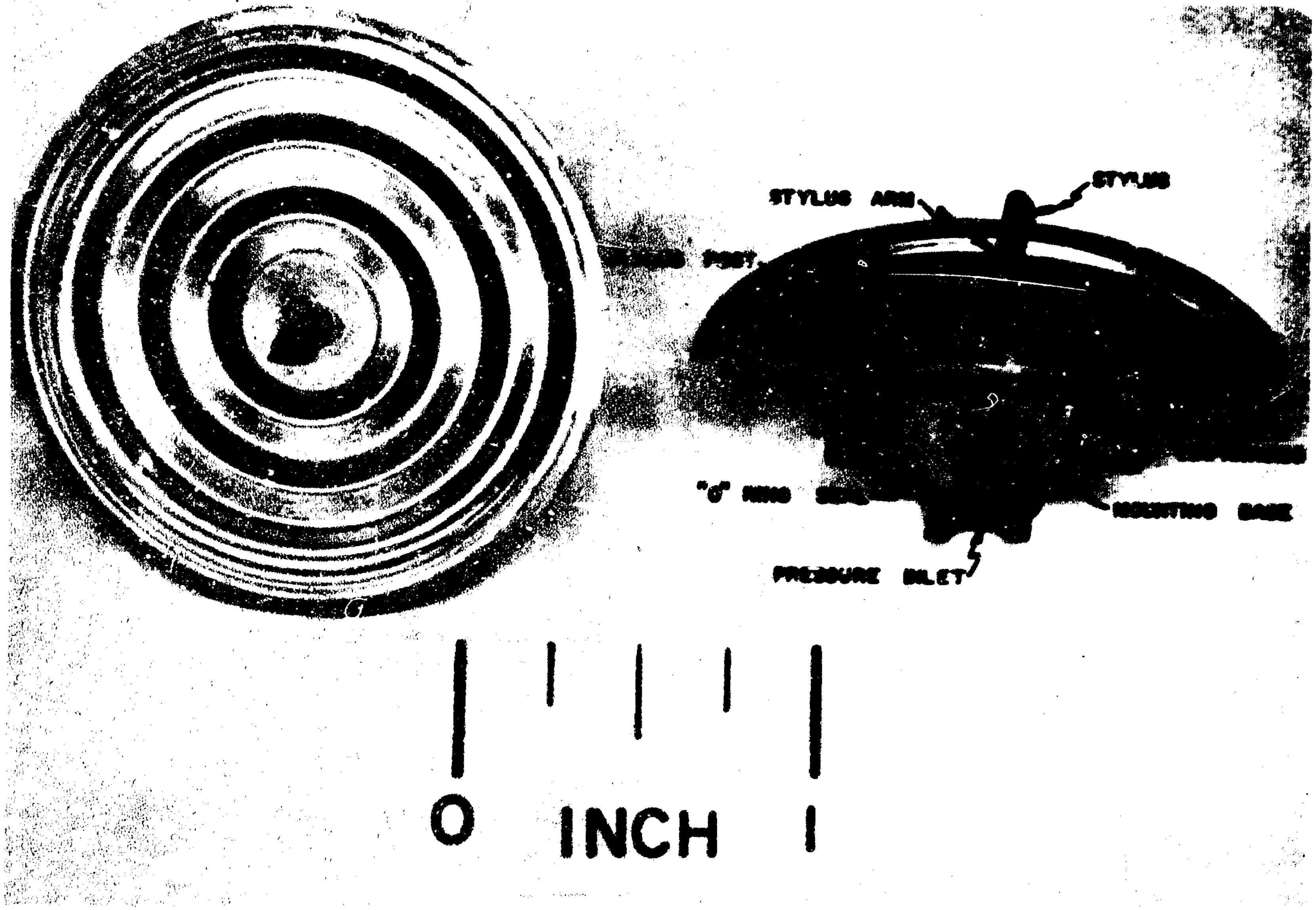


Fig. 2.14—Self-recording gauge pressure element.

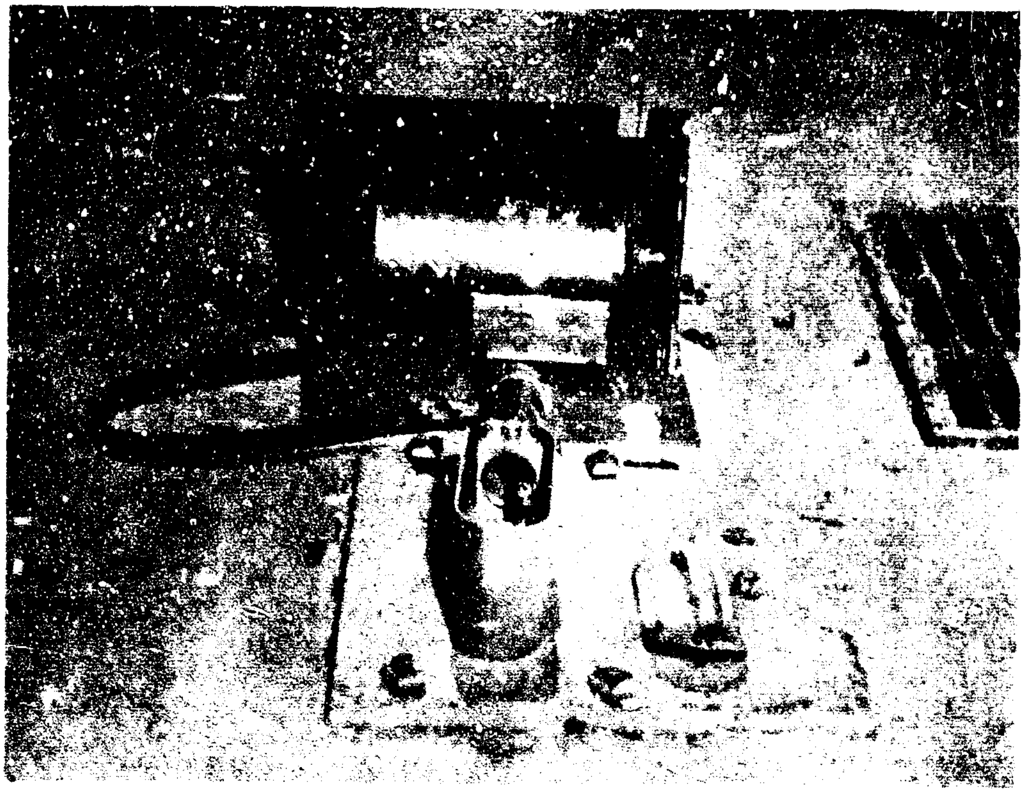


Fig. 2.15—Large-displacement gauge.

Fig. 2.16—Small-displacement gauge.

Fig. 2.17—Special displacement gauge, Project 30.2 (bending of door).

Fig. 2.18—Special displacement gauge, Project 30.2 (movement of door)

Fig. 2.19—Special displacement gauge, Project 31.5.

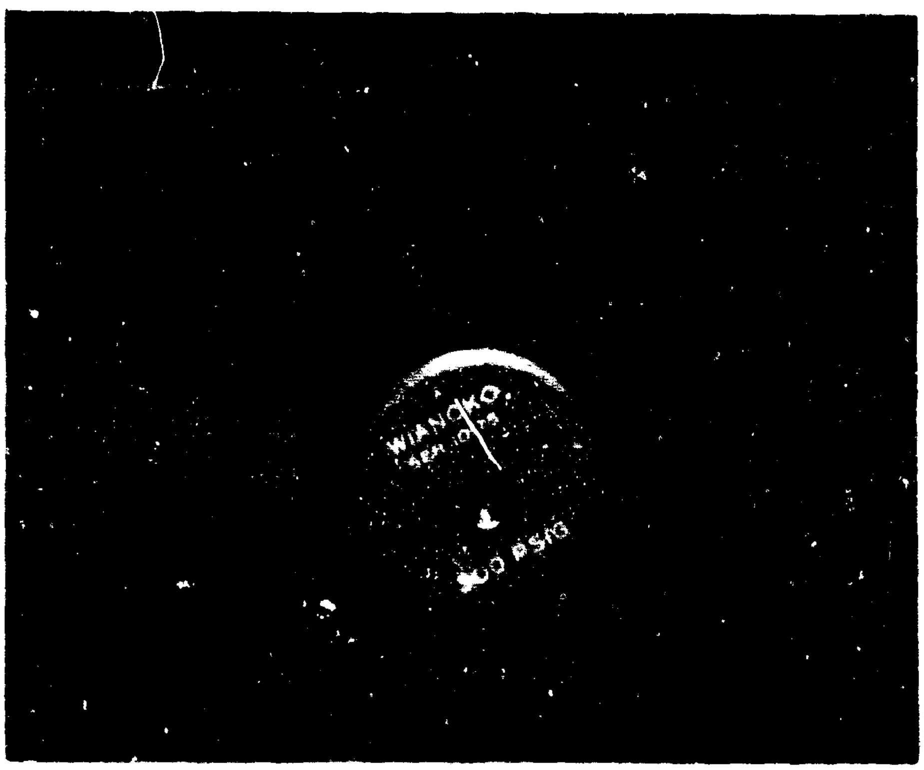


Fig. 2.20—Wiancko pressure gauge

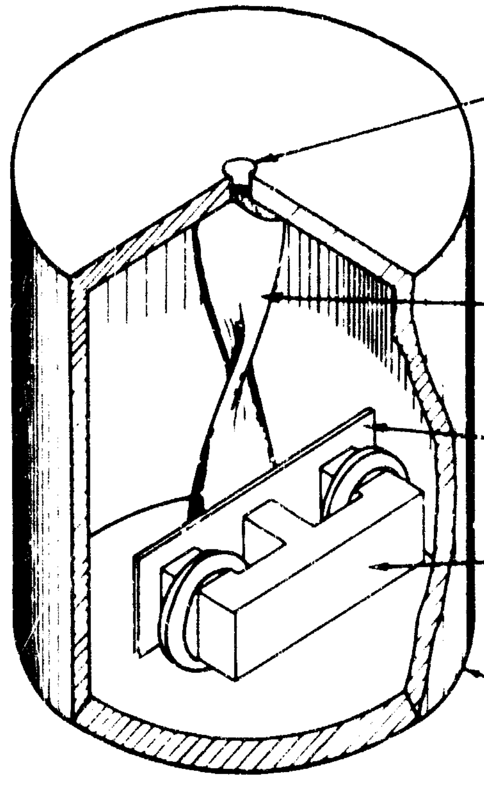


Fig. 2.21—Schematic drawing of pressure-gauge ccnfiguration.

Fig. 2.22—Sandia dynamic-pressure gauge.

Fig. 2.23—Wiancko accelerometer.

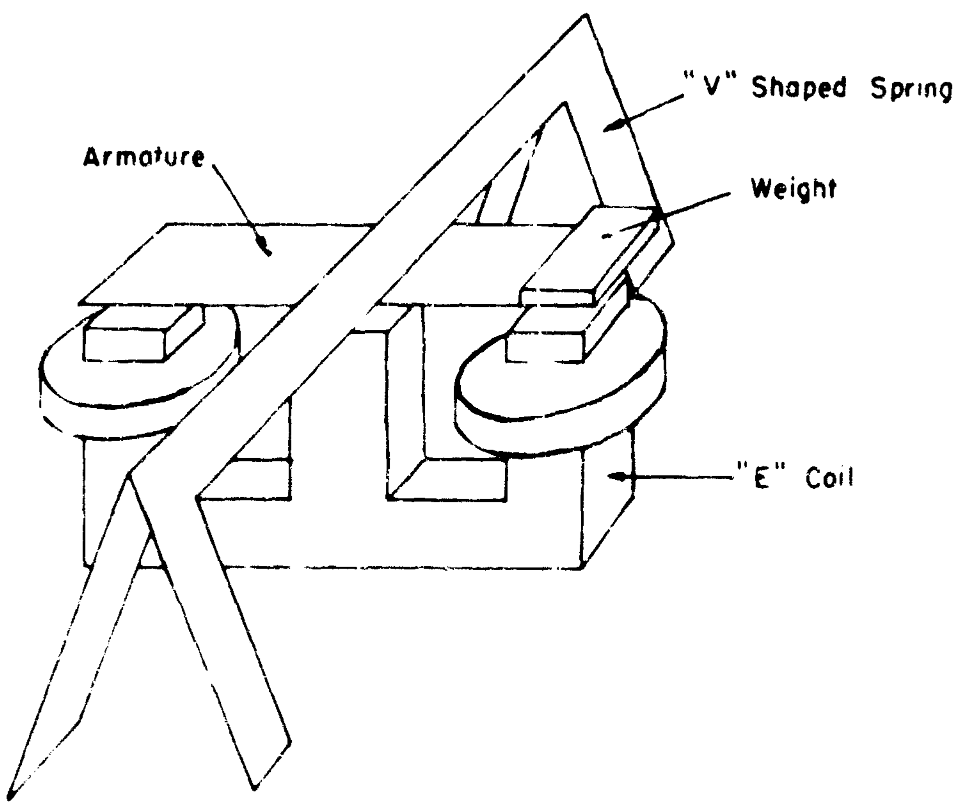


Fig 2.24—Schematic drawing of accelerometer spring mechanism

Fig. 2.25—Wiancko-Carlson earth-pressure gauge.

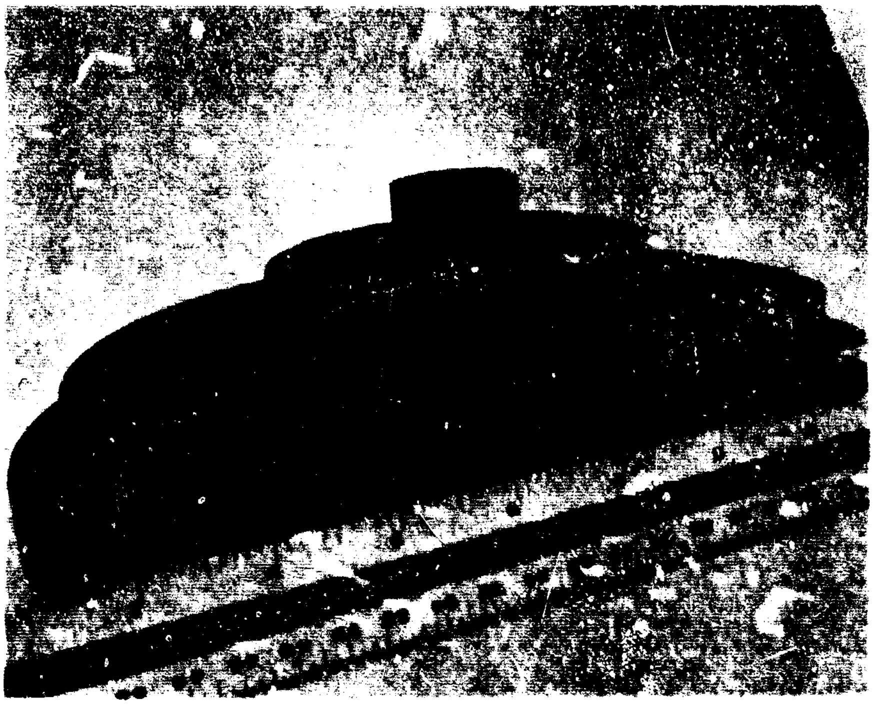


Fig. 2.26—Cutaway photograph of earth-pressure gauge sensing mechanism.

Fig. 2.27—Installation of pressure-time gauge using cast-in mount.

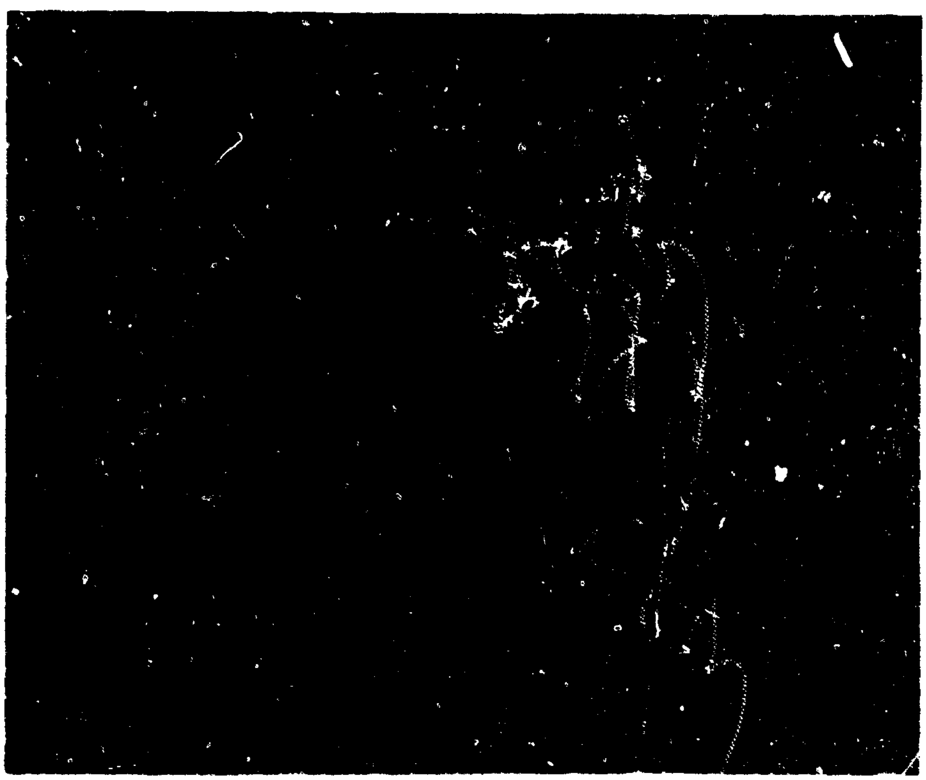


Fig. 2.28—Complete surface installation of pressure-time gauge.

Fig. 2.29—Pressure-time gauge mounted for fill-time measurement.

Fig. 2.30—Mount for 7-ft self-recording dynamic-pressure gauge

Fig. 2.31—BRL dynamic-pressure gauge adapted to standard AFSWP mount.

Fig. 2.32—Typical installation of BRL displacement gauges

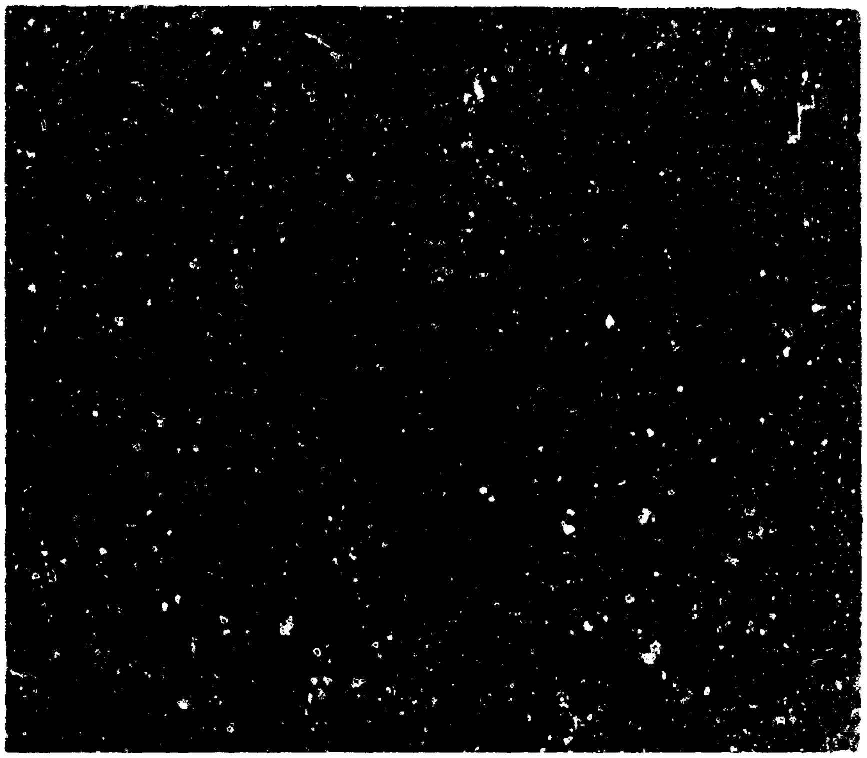


Fig. 2.33—Typical installation of Wiancko pressure gauges.

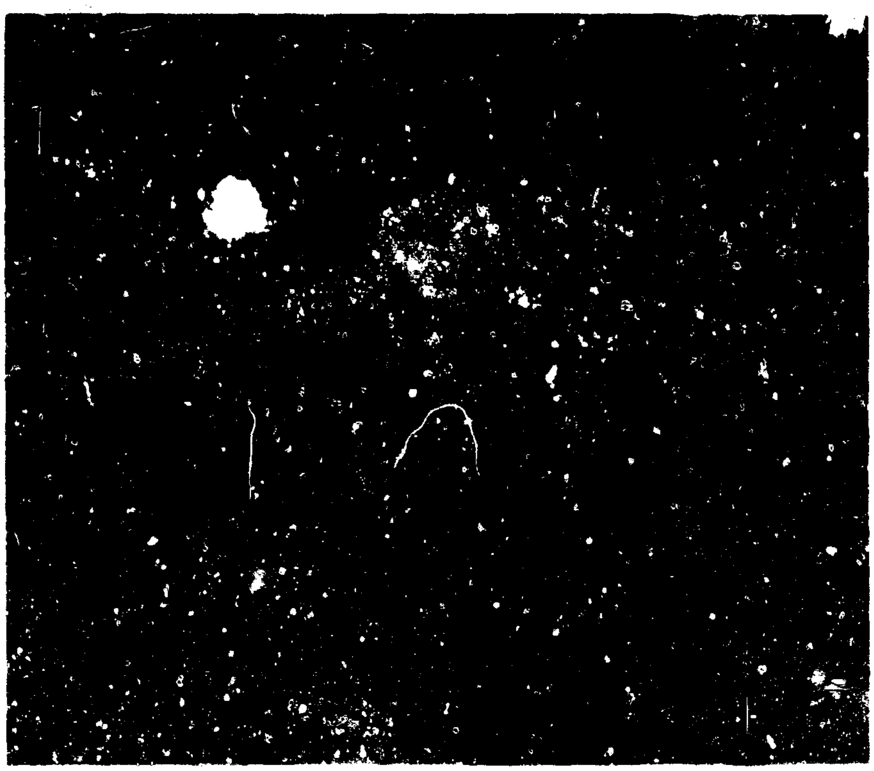


Fig. 2.34—Sandia dynamic-pressure gauge on standard AFSWP (Sandia) mount.

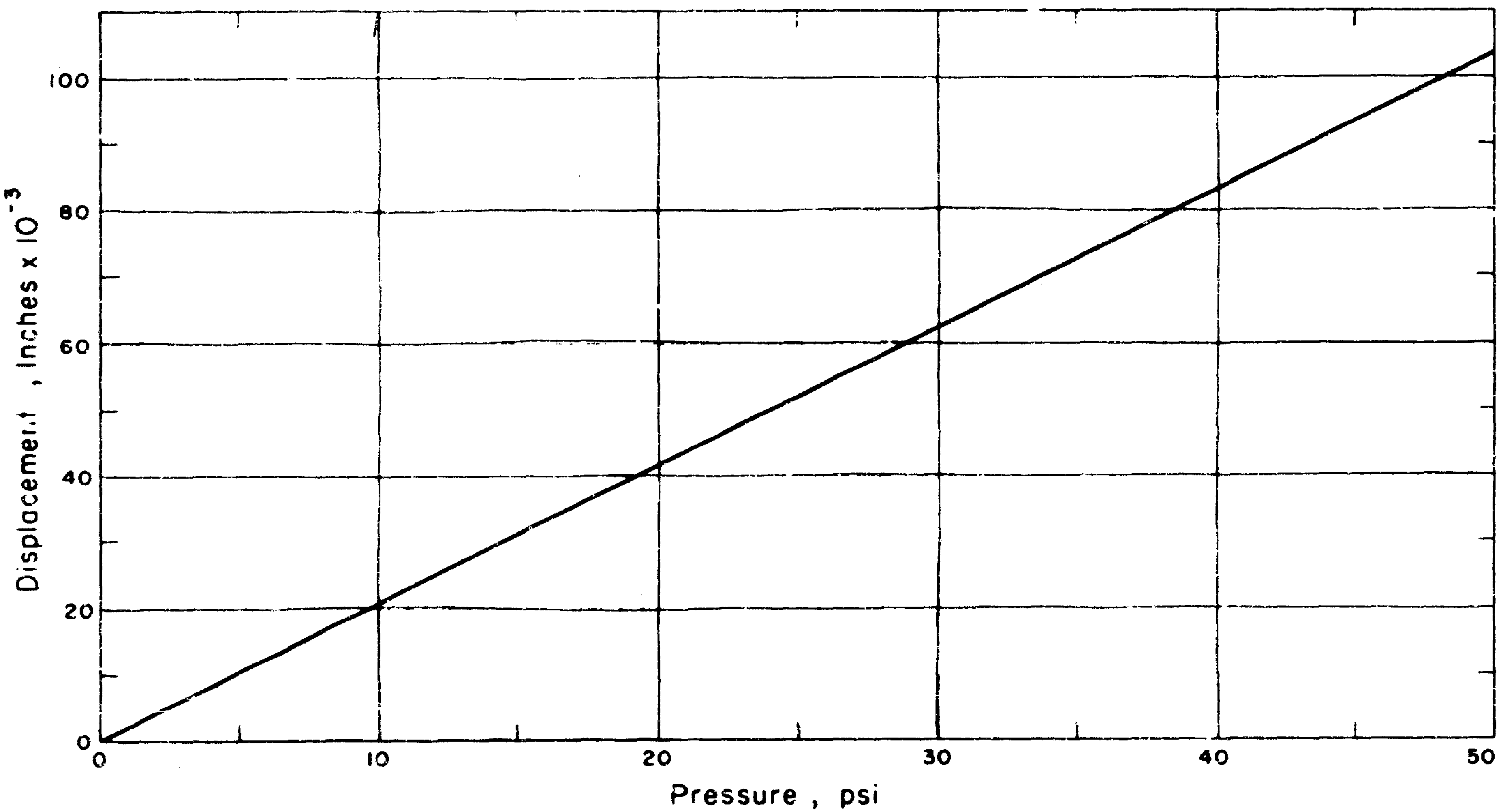
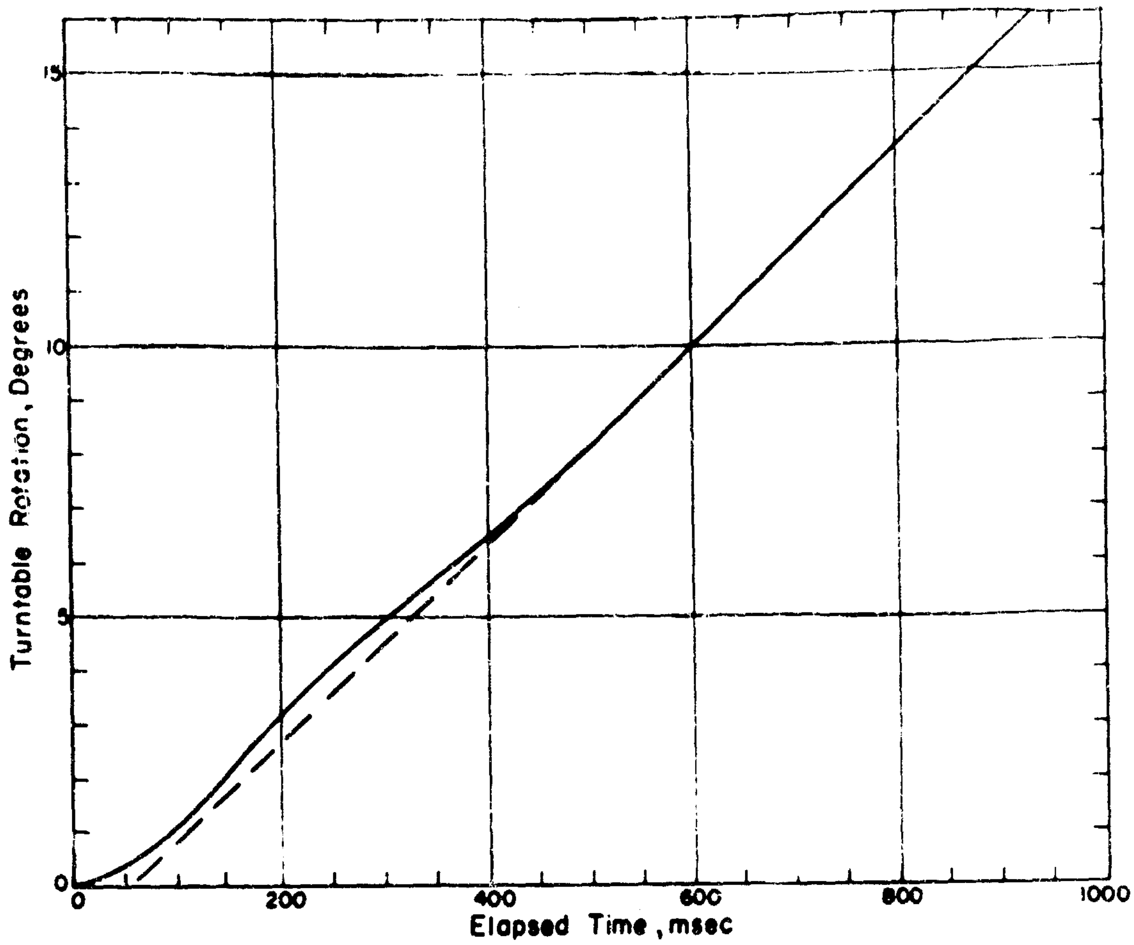
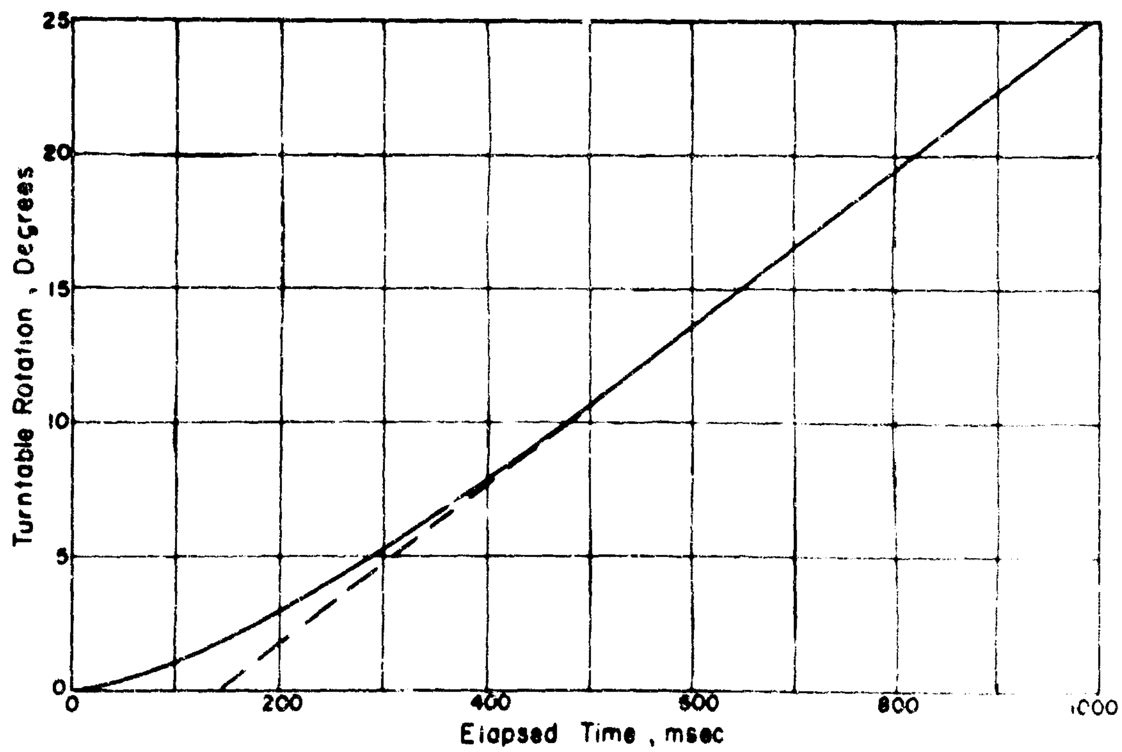


Fig. 2.35—Typical curve of pressure vs. displacement of self-recording gauge capsule.



(a)



(b)

Fig. 2.36—Angular displacement vs. time of self-recording gauge motor: (a) 3-rpm motors; (b) 10-rpm motors.

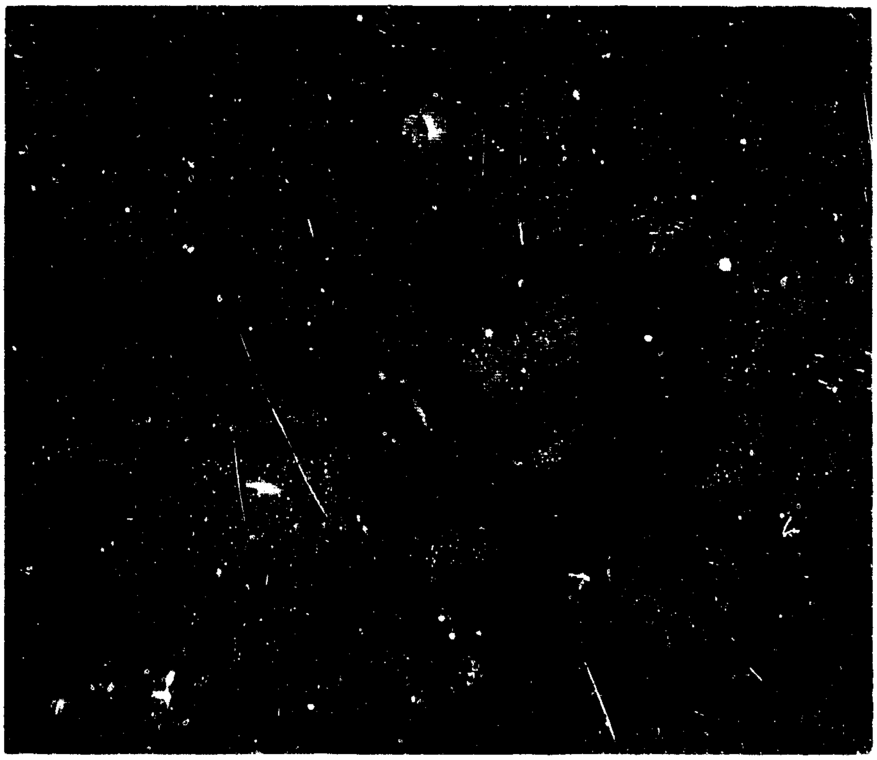


Fig. 2.37—Small-displacement gauge calibration.

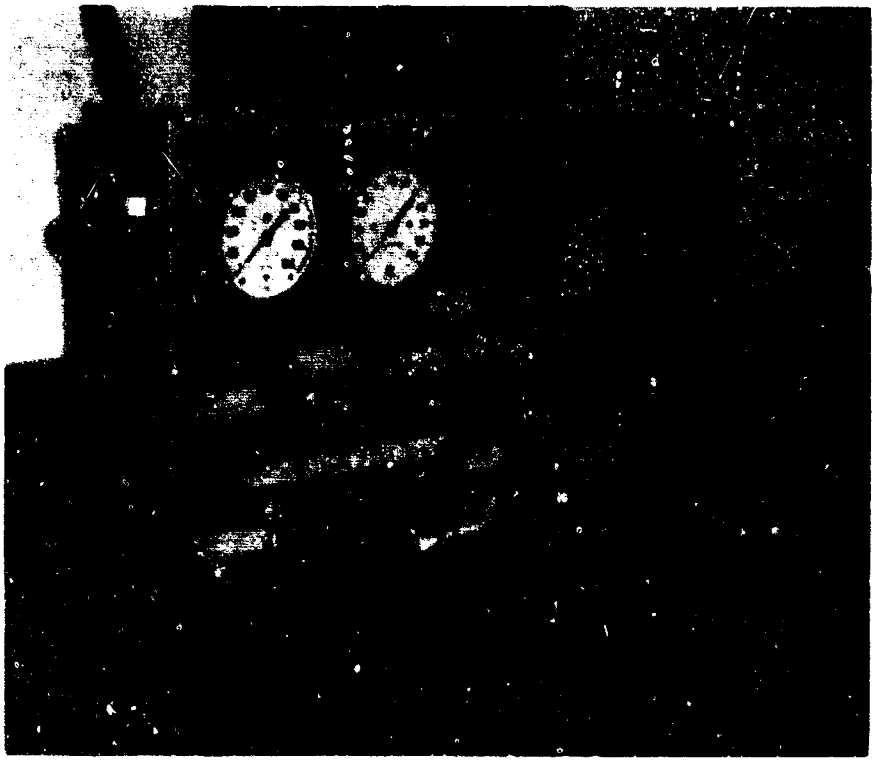


Fig 2.38—Typical calibration of Wiancko pressure gauges.

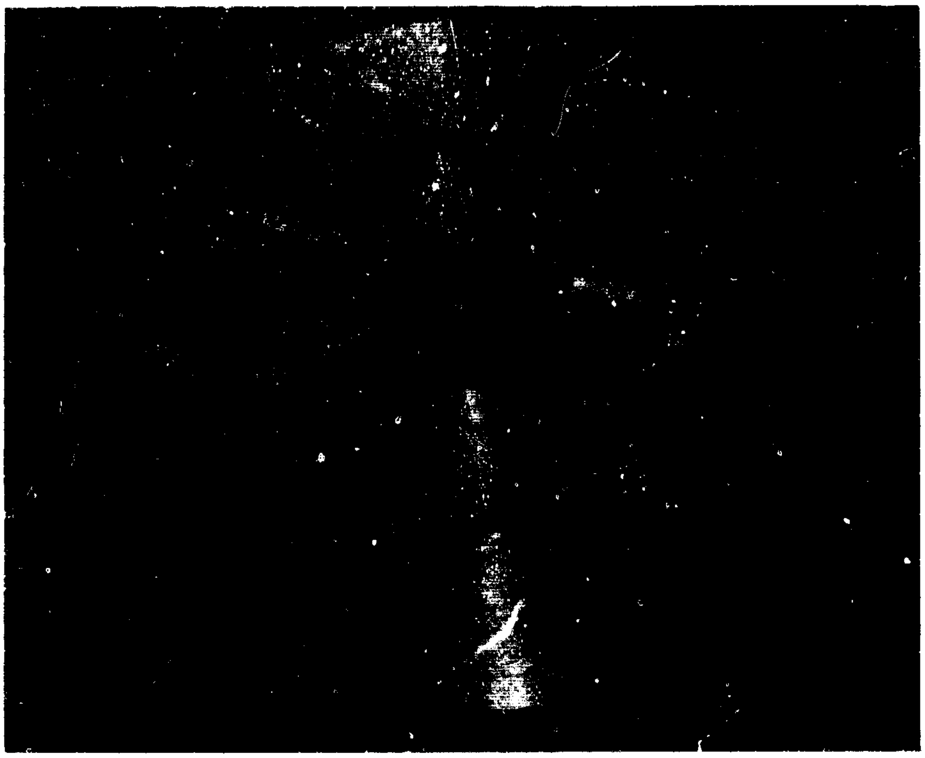


Fig. 2.39—Calibration of accelerometer.

Fig. 2.40—Calib ation of earth-pressure gauge.

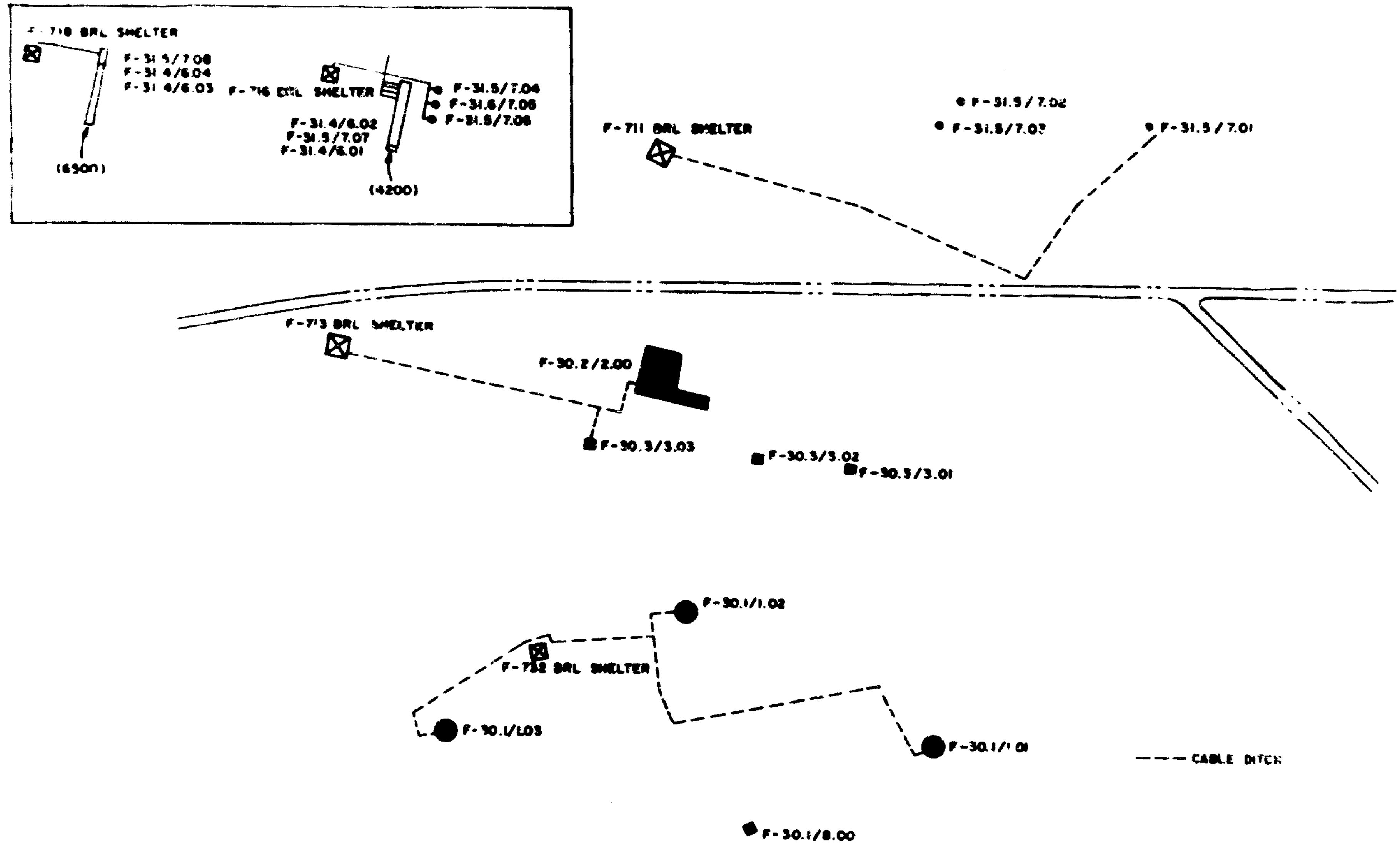


Fig. 2.41—Field layout

Chapter 3

RESULTS AND DISCUSSION

3.1 ACCEPTABILITY OF DATA

The operation of the gauges and recording equipment is summarized in Table 3.1. The comment for each gauge indicates the technical success of the measurement.

In brief, from an instrumentation point of view, 52 records of 75 electronic measurements were perfect, 17 records of 37 self-recording measurements were perfect, and 13 records of 15 peak-recording methods were perfect. In addition, 6 electronic records were amenable to interpretation without speculation, and 18 self-recording records gave usable peak-value indications. In several instances, "no apparent record" is noted. Here, even though all indications are that the equipment was functioning properly, the record was not numbered with those considered usable.

3.2 ANOMALIES AND THEIR TREATMENT

In general, the results of the instrumentation were considered satisfactory. A better percentage of records was obtained from electronic gauges than from the self-recording gauges.

Failure to receive records from electronic gauges was principally due to the gauge's being either under ranged or over ranged. Gauges that were principally under ranged were the earth-pressure gauges; in these cases the signals received from the gauges were saturated, giving rise to a flat plateau. The over-ranged gauges were principally the accelerometers. Here the deflections of the records were small, and the reading of these records to any degree of accuracy is questionable. In several cases, structural failure was the cause of an incomplete record being obtained from the electronic gauges. For example, such was the case of the displacement gauges located in the ramp of Structure 30.2 8002: The wires were broken when the wall of the ramp collapsed.

Because of the severe radiation-induced electromagnetic pulse present at zero time, a signal was induced on the recording mechanism. Often the base line returned to zero before the blast arrived at the transducer, in which case the records were immediately usable. However, in some cases, the records experienced a permanent zero shift. In these cases, the records obtained from the electronic gauges required adjustment of the calibration data to compensate for the zero shift.

The self-recording gauge failures resulted from preinitiation or failure to initiate. Those to be initiated by hard-wire failed because of defects in circuitry or a cut wire. A larger portion of gauge failures was due to preinitiation. The gauges most affected were those that were to have been initiated by photocell. In this case, the preinitiation of gauges could have been accomplished by a strong beam of light, such as the headlight from a vehicle.

Records of the peak-pressure recorders are somewhat questionable, in view of the fact that the structures were nominally pressure-sealed and no appreciable damage to the structures resulted. The deflections noted on the records could very well result from the accelerations sustained by the structure.

TABLE 3.1 — CLASSIFICATION OF DATA*

Project/Structure	Gauge No.	Type of measurement	Comments
30.1/8001.01	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Bad record
	P5	Pressure	Good record
	A23V	Acceleration	Fair record, zero shift
	A26H	Acceleration	Bad record
	A27V	Acceleration	Fair record
	A28H	Acceleration	Fair record
30.1/8001.02	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Bad record
	P4	Pressure	Good record
	P5	Pressure	Good record
	A23V	Acceleration	Fair record
	A24H	Acceleration	Fair record
	A29V	Acceleration	Bad record
	A30H	Acceleration	Bad record
30.1/8001.03	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	No apparent record
	P5	Pressure	Good record
	P6	Pressure	Good record
	P7	Pressure	Fair record
30.2/8002	P1	Pressure	Good record, shift during shot
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Bad record
	P5	Pressure	Good record
	E6	Earth pressure	Good record
	E7	Earth pressure	Good record
	E8	Earth pressure	Good record
	E9	Earth pressure	Good record
	E10	Earth pressure	Bad record
	E11	Earth pressure	Good record
	E12	Earth pressure	Good record
	E13	Earth pressure	Good record
	E14	Earth pressure	Good record
	E15	Earth pressure	Bad record
	E16	Earth pressure	Bad record
	D1	Deflection	Good record

*The symbols used to specify gauge type are defined as follows:

Electric gauges	Self-recording gauges	Peak recording gauges
A, accelerometer	SP, pressure	PD, displacement
D, displacement	SQT, total pressure (Q-gauge)	PP, peak pressure
E, earth pressure	SQS side-on pressure (Q-gauge)	
D, dynamic pressure (Q-gauge)		
S, side-on pressure (Q-gauge)		

Numbers following the symbols are gauge numbers.

Table 3.1 — (Continued)

Project/Structure	Gauge No.	Type of measurement	Comments
30.2/8002	D2	Deflection	Bad record
	D3	Deflection	Good record
	D4	Deflection	Good record
	D5	Deflection	Good record
	D6	Deflection	Good record
	D7	Deflection	Good record
	D8	Deflection	Good record
	D9	Deflection	Good record
	D10	Deflection	Good record
	D11	Deflection	Good record
	D12	Deflection	Good record
	D13	Deflection	Good record
	D14	Deflection	Good record
	D15	Deflection	Bad record
	D16	Deflection	Gauge failed
	D17	Deflection	Gauge failed
	D18	Deflection	Bad record
	QD	Dynamic pressure	Bad record
	QS	Dynamic pressure	Good record
	SQT	Dynamic pressure	Peak pressure only
	SQS	Dynamic pressure	Peak pressure only
	SP1	Pressure	Good record
	SP2	Pressure	Peak pressure only
30.3/8003.01	SP	Pressure	Good record
	PP	Peak pressure	Peak pressure only
30.3/8003.02	SP	Pressure	Bad record
	PP	Peak pressure	Peak pressure only
30.3/8005.03	SP	Pressure	Good record
	PP	Peak pressure	Peak pressure only
	D1	Deflection	Good record
	D2	Deflection	Good record
31.4/8006.01	SP1	Pressure	Good record
	SP2	Pressure	Good record
	SP3	Pressure	Good record
	PP	Peak pressure	Good record
	PD1	Deflection	Structure failed
	PD2	Deflection	Good record
	PD3	Deflection	Good record
	PD4	Deflection	Good record
	PD5	Deflection	Good record
	D1	Deflection	Good record
31.4/8006.03	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
	SP3	Pressure	Good record
	PD1	Deflection	Good record
	PD2	Deflection	Good record
	PD3	Deflection	Good record
	PD4	Deflection	Good record
	PD5	Deflection	Good record
31.5/8007.01	D1	Deflection	Gauge failed
	SP1	Pressure	Peak pressure only
	SP2	Pressure	No record

Table 3.1 — (Continued)

Project/Structure	Gauge No.	Type of measurement	Comments
31.5/8007.02	D1	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Good record
31.5/8007.03	D1	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
31.5/8007.04	D1	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
31.5/8007.05	D1	Deflection	Good record
	SP1	Pressure	Good record
	SP2	Pressure	Peak pressure only
31.5/8007.06	D1	Deflection	Good record
	SP1	Pressure	Good record
	SP2	Pressure	Good record
31.5/8007.07	D1	Deflection	Good record
	D2	Deflection	Good record
	D3	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
	SP3	Pressure	Peak pressure only
	SP4	Pressure	Good record
	SP5	Pressure	Good record
	SP6	Pressure	Good record
	SP7	Pressure	Good record
31.5/8007.08	D1	Deflection	Good record
	D2	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Good record
	SP3	Pressure	Good record
	SP4	Pressure	Peak pressure only
	SP5	Pressure	Good record

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 GAUGE IMPROVEMENTS

As is generally the case during the course of a project of this type, several methods suggest themselves to ease the workload for completion of the instrumentation requirements and to improve the caliber of records obtained. The calibration of displacement gauges that were to measure displacement of a minute fraction of an inch was critical. Much time was spent in calibrating these gauges to ensure that the calibration was valid. A modification of the calibration apparatus is being considered.

The difficulties encountered with initiation have been diagnosed, and several new experimental circuits have been developed.

4.2 RECORDER IMPROVEMENTS

The Webster-Chicago recording equipment proved satisfactory during shot Priscilla. However, this system has been in use since Operation Greenhouse. It has been rebuilt and modified several times. Owing to this extended service and repeated rough handling in shipment, it is felt that the system is rapidly deteriorating, as well as becoming obsolete.

It is recommended that the recording system either be replaced with a more-modern and more-compact system or that a new system be built along the present lines of the Webster-Chicago system, incorporating the latest electrical components available.

4.3 SCHEDULE IMPROVEMENTS

As has often occurred during past test operations, usually owing to the very short, tight construction time schedule, the structures were not actually complete at the time scheduled for instrumentation to begin. Therefore considerable time and motion of the BRL instrumentation personnel were lost because of the unavoidable interference of construction personnel concurrently working in the test area. It is strongly recommended that the time-period schedule specified prior to an operation for instrumentation calibration and installation be adhered to in order to allow adequate time for completion and readiness.

Appendix A

MEMORANDUM OF UNDERSTANDING REGARDING INSTRUMENTATION OF STRUCTURES

1. In view of the plan for Operation Plumbbob whereby:

a. The Ballistic Research Laboratories (BRL) will be responsible for supplying electronic instrumentation for several Program 3 structures projects in the Department of Defense (DOD) Weapons Effects Program, Operation Plumbbob. Specifically, these are Projects 3.1, 3.2, 3.3, and 3.6, and will involve approximately a total of 100 electronic channels.

b. In addition to the instrumentation indicated in the preceding paragraph, in conformance with previous mutual agreement between Headquarters, Armed Forces Special Weapons Project (AFSWP) and Federal Civil Defense Administration (FCDA), Civil Effects Test Group (CETG), it has already been determined that BRL also will be responsible for supporting the FCDA (CETG) projects on Frenchman Flat, Operation Plumbbob, with up to 85 electronic channels of instrumentation.

c. The physical layout of the AFSWP Program 3 structures projects and the FCDA projects will place them in relatively close proximity. The capability limitations of the total number of channels of BRL recording equipment is to be such that for BRL to properly accomplish this major instrumentation effort it will be necessary for BRL to utilize various channels of a single recording installation in the several instrumentation shelters, for more than one, i.e., several, different projects. Such joint utilization should also provide the structures instrumentation requirements at maximum over-all economy of manpower, material, and money.

d. Because of the close interrelationship of the instrumentation of the structures as described above, the scope of this effort, and the inherent problems of administration and financial accountability for the various portions of this effort, it is deemed very desirable to establish a separate AFSWP project, and a similar, affiliated, separate FCDA (CETG) project, to facilitate accomplishment of the structures instrumentation

2. Accordingly, the organizations concerned: FC, AFSWP; FCDA; CETG; and BRL, do hereby agree, for the mutual benefit of all in this effort for Operation Plumbbob, that:

a. There is hereby established, for the reasons indicated above, the following AFSWP project:

Project No: 3.7

Agency: BRL/AFSWP

Shot participation: DOD shot only

Title: Structures Instrumentation

Project Officer: J. J. Meszaros
Explosion Kinetics Branch
Terminal Ballistic Laboratory
Aberdeen Proving Ground, Maryland
Phone: Aberdeen 1000
Ext: 42222

Objective: To procure and operate suitable instrumentation to obtain the data required by Projects 3.1, 3.2, 3.3, and 3.6

Description and Experimental Procedure: It will be the responsibility of each of the Project Officers, Projects 3.1, 3.2, 3.3, and 3.6, to work closely with and assure themselves that BRL is adequately meeting all of the instrumentation requirements of their individual projects. Responsibilities of BRL include obtaining the instrumentation requirements from each of the individual projects and, as appropriate, consolidating these requirements for the purpose of procuring and operating suitable instrumentation to obtain the data required by the individual projects.

b. There is hereby established, for the reasons indicated above, the following FCDA (CETG) project:

Project No: 30.5	Title: Shelters and Structures Instrumentation
Agency: BRL/FCDA Shot participation: DOD shot only	Project Officer: J. J. Meszaros Explosion Kinetics Branch Terminal Ballistic Laboratory Aberdeen Proving Ground, Maryland Phone: Aberdeen 1000 Ext: 42222

Objective: To procure and operate suitable instrumentation to obtain the data required by FCDA shelters and structures projects.

Description and Experimental Procedure: It will be the responsibility of the Program Director, FCDA (CETG) Shelter Program, to work closely with and assure that BRL is adequately meeting all of the instrumentation requirements of the FCDA individual projects. Responsibilities of BRL include obtaining the instrumentation requirements for each of the individual projects and, as appropriate, consolidating these requirements for the purpose of procuring and operating suitable instrumentation to obtain the data required for the individual projects.

c. The close relationship of the two foregoing structures instrumentation projects is indicated by the following procedures hereby agreed to:

Monthly Status Reports and Construction Requirements:

BRL will prepare and submit in the usual manner to WET, FC, AFSWP, the normal Monthly Status Reports and Construction Requirements for the consolidated requirements of Project 3.7, including proposed project personnel, materiel, equipment, support required, construction required, etc. These consolidated requirements will, of necessity, include those requirements necessary to accomplish the instrumentation of each of the AFSWP Projects, 3.1, 3.2, 3.3, and 3.6, and also for those FCDA (CETG) structures projects on Frenchman Flat.

This will actually mean that the total BRL consolidated requirements for the structures instrumentation of AFSWP Project 3.7 and FCDA (CETG) Project 30.5 will be handled by, and appropriate action taken through, WET, FC, AFSWP channels, i.e., for the following requirements normally covered by the Monthly Status and the Construction Requirements Reports: (1) Instrumentation Experimental Plan; (2) Timing Signal Requirements; (3) Communications Requirements; (4) Radiation Monitors; (5) Photographic Requirements; (6) Office Equipment Requirements; (7) Vehicle Requirements (for special consideration of this item, see below, Financial and Budgetary Considerations); (8) Equipment Purchased (control of, and title to, all equipment will remain with the AFSWP Equipment Pool, since the equipment to be purchased is to be a relatively small component part of and should be considered a modification to already existing AFSWP equipment); (9) Construction Requirements and Changes; (10) Project Personnel and Clearance Data.

BRL will also furnish copies of these reports to Projects 3.1, 3.2, 3.3, and 3.6, and also FCDA (CETG), to keep them advised.

Financial and Budgetary Considerations:

Introduction. Based upon the above consolidated requirements, BRL will prepare a total consolidated budget for AFSWP Project 3.7 and FCDA (CETG) Project 30.5. The total consolidated budget will then be prorated between the various projects approximately on the basis of the number of channels utilized by each project. By mutual agreement between WET,

FC, AFSWP and FCDA (CETG), based on the approximate total number of instrumentation channels to be used by each, 60 per cent of the total budget will be chargeable to AFSWP Project 3.7 and 40 per cent will be chargeable to FCDA (CETG) Project 30.5.

Of the 60 per cent of the total budget chargeable to AFSWP Project 3.7, based on the approximate total number of instrumentation channels to be used by each, the projects involved will be chargeable as follows:

Project 3.1	30 per cent
Project 3.2	5 per cent
Project 3.3	5 per cent
Project 3.6	60 per cent

Timing Signals. The cost of the timing signal requirements is an item not normally budgeted for by each specific project, but is budgeted for a lump sum total support cost for timing signals furnished all AFSWP projects by the AEC subcontractor concerned, EG&G. However, since the timing signals requirements represent a sizeable item of cost, it is agreed that AFSWP (in behalf of Project 3.7) will assume 60 per cent of the total estimated cost of all timing signal requirements for BRL structures instrumentations to be furnished by EG&G, and that FCDA (CETG) will assume 40 per cent.

Vehicles. In recognition of: (1) the difficulties inherent in, and the normal lack of specific project budgeting for, project-used vehicles and therefore the difficulty in prorating vehicle costs, and (2) the general supplementary administrative support to be furnished by WET, FC, AFSWP, to the FCDA (CETG) portion of the BRL structures instrumentation effort (such as processing the combined personnel, equipment, office requirements, and materiel requirements), it is further agreed, supplementing the foregoing Financial and Budgetary Prorating, that FCDA (CETG) will furnish the total number of vehicles required for this effort by BRL (probably about eight: (three-carryalls; five $\frac{1}{2}$-ton pickup trucks), from the AEC, NTS Motor Pool. Fuel and service requirements, routine maintenance, including financial responsibility for same, and control of these vehicles, will be the responsibility of the AEC, NTS Motor Pool in accordance with arrangements between AEC and FCDA (CETG).

General. All of the above percentage allocation figures will be used throughout the Operation Plumbbob, unless it becomes obvious that due to major changes in the current plans of the number of instrumentation channels required, a revised set of percentage allocations should be adopted.

Copies of the consolidated budget, including the prorated shares for the participating projects, as prepared by BRL and forwarded to WET, FC, AFSWP, will also be furnished to the participating Projects 3.1, 3.2, 3.3, and 3.6, and also to FCDA (CETG).

Field Work Order Requests: For all field work order requests written by BRL to accomplish items, such as all trenching, for Project 3.7/30.5, LVBO, AEC, will be requested to total monthly all such work orders charged against Project 3.7/30.5 and to prorate these costs on the basis of 60 per cent for Project 3.7 and 40 per cent for Project 30.5. These work orders will include all those for all BRL structures instrumentation work. The 60 per cent for Project 3.7 will be redistributed to the participating AFSWP projects at the close of the Operation by WET, FC, AFSWP, on the same percentage basis indicated under the financial and budgetary considerations paragraph above.

The submission of all such field work orders by BRL will be through the Requirements Branch, WET, FC, AFSWP, organization channels, for implementation. Appropriate copies of such field work orders will also be furnished to FCDA (CETG).

Funding: Subject to the above, BRL will receive funds from FC, AFSWP, as appropriate, chargeable to Projects 3.1, 3.2, 3.3, and 3.6 for their respective prorated percentage of 60 per cent of the total combined budget for Project 3.7 structures instrumentation.

BRL will receive funds direct from FCDA, as appropriate, for the 40 per cent of total combined budget for FCDA (CETG) Project 30.5 structures instrumentation.

Field Work Order Requests for structures instrumentation projects will be chargeable on a prorated basis: AFSWP Project 3.7, 60 per cent and FCDA (CETG) Project 30.5, 40 per cent, directly against FC, AFSWP and FCDA funds, respectively.

Summary: It is believed the above arrangements, as agreed to by the appropriate representatives of FC; AFSWP; FCDA, CETG; and BRL at a conference at the office of USAEC, Las Vegas Branch Office, Las Vegas, Nevada, on 17-18 October 1956, will enable this structures instrumentation effort for Operation Plumbbob to be accomplished in the most expeditious, administratively equitable basis, to the satisfaction of all interested parties.

3. The senior representatives present from each of the organizations concerned, who were at the conference at which the above memorandum of understanding was drawn up and agreed upon, were:

H. D. Pickett Captain, USN Asst. Deputy Chief of Staff, WET, FC, AFSWP	E. R. Saunders Coordinating Director of Technical Tests, FCDA
J. J. Meszaros Chief, Explosion Kinetics Branch Ballistic Research Laboratories	R. L. Corsbie Director, CETG

To facilitate earliest action on this major BRL instrumentation effort for Operation Plumbbob, it was agreed that for practical purposes the agencies concerned, especially BRL, would proceed at once on the premise that this memorandum of understanding was acceptable to the parent organizations of all concerned.

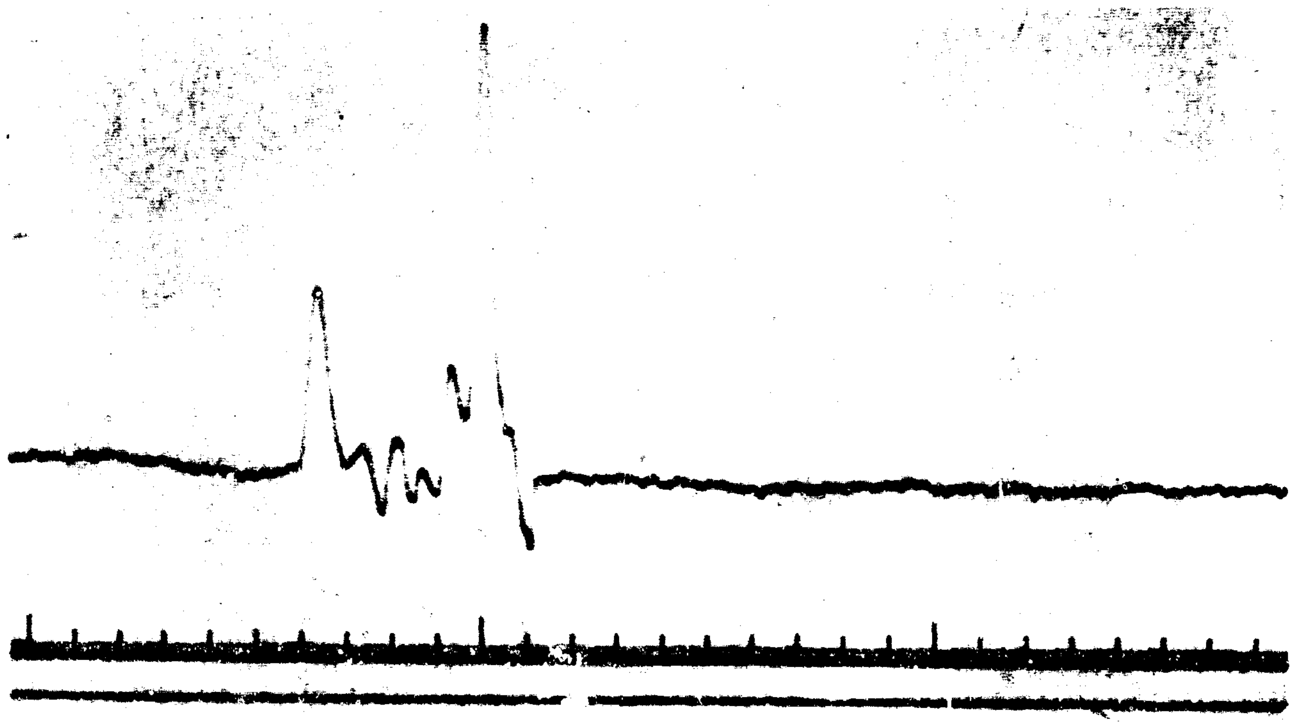
4. Accordingly, the above memorandum of understanding, as drawn up and now prepared in finished form, is furnished for the confirming validation or signature by the appropriate representative of each parent organization concerned:

s/HARRY D. PICKETT t/Captain, USN Asst. Deputy Chief of Staff Weapons Effects Tests (FC, AFSWP Representative)	s/WILLIAM S. HEFFELFINGER t/Assistant Administrator General Administration (FCDA Representative)
s/CHARLES L. REGISTER t/Colonel, Ord Corps Director, Ballistic Research Laboratories (BRL Representative)	s/ROBERT L. CORSBIE t/Director, Civil Effects Test Group Nevada Test Organization (CETG Representative)

Appendix B

RECORDS

Appendix B presents photographs of a representative group of electronic channel original records and linearized plots of these records (Figs. B.1 to B.14). Also presented are linearized plots of all self-recording pressure-time gauges determined as useable in Table 3.1. With each group of plots there is a sketch identifying the plots with their station locations.



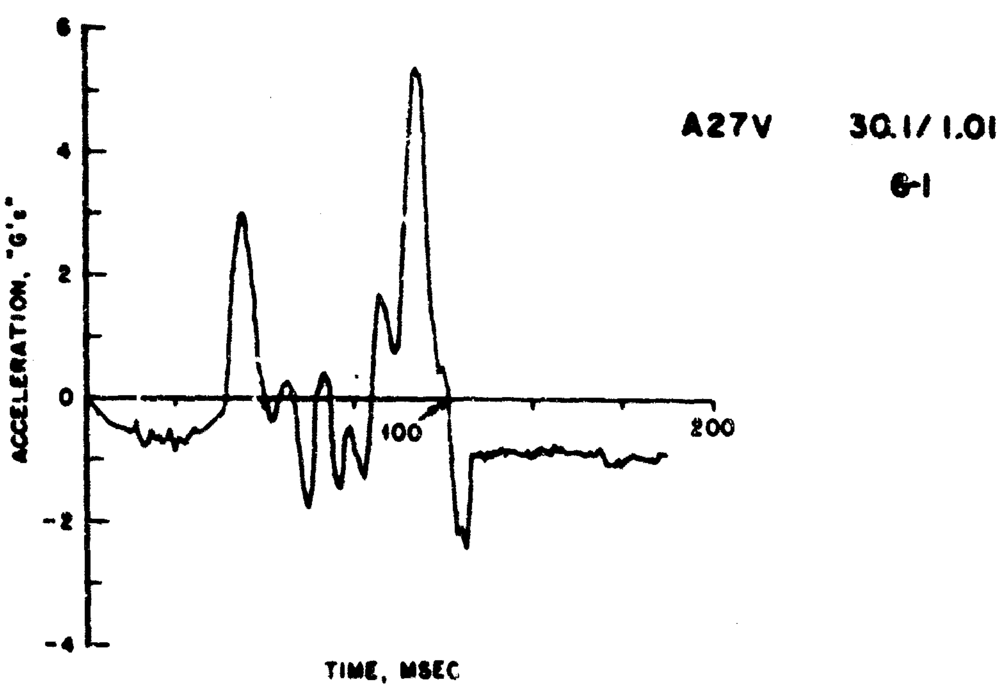


Fig. B.1—Acceleration-time record, gauge A27V, stations 30.1/1.01

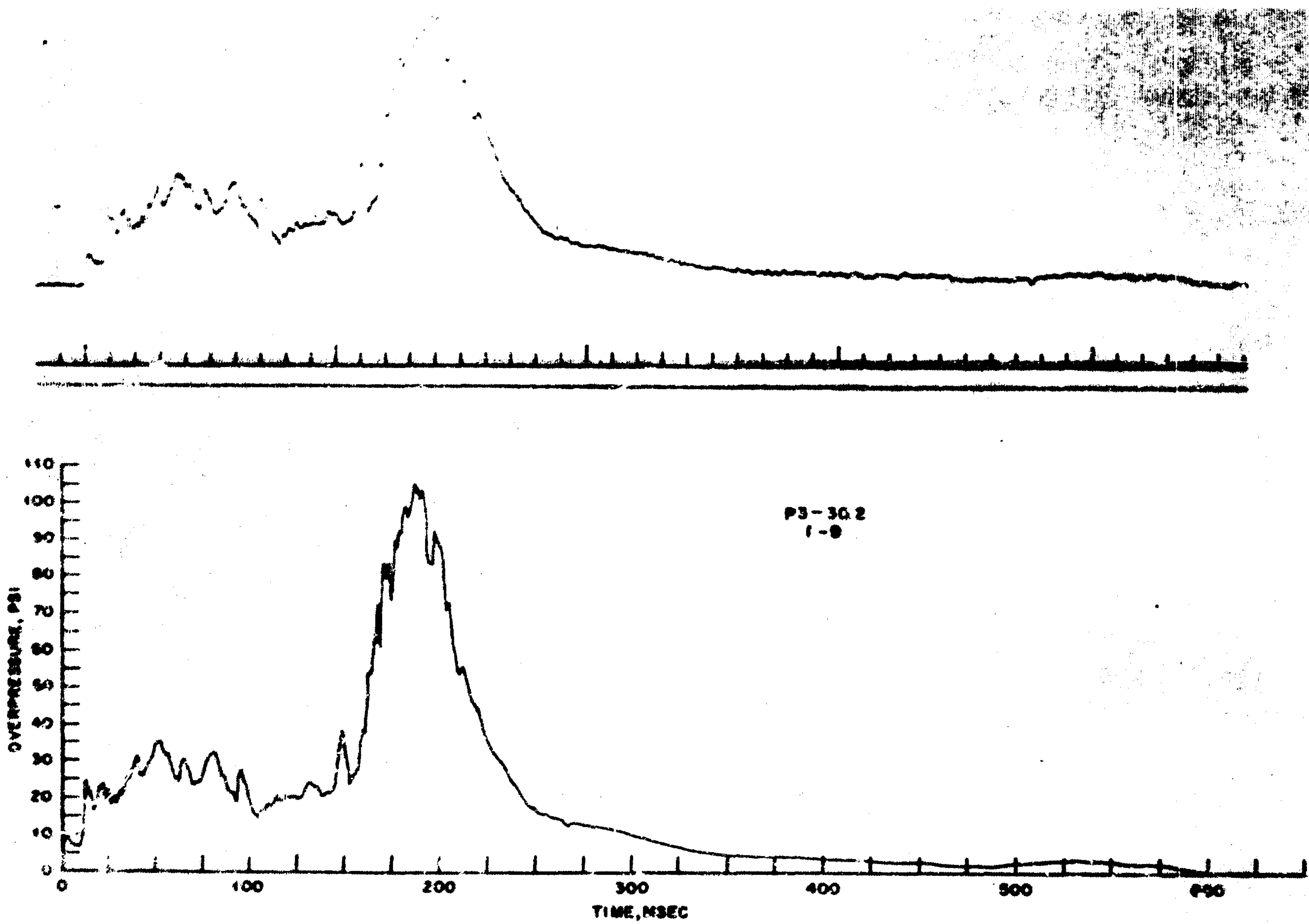


Fig. B.2—Overpressure-time record, gauge P3, stations 30.2/2.00.

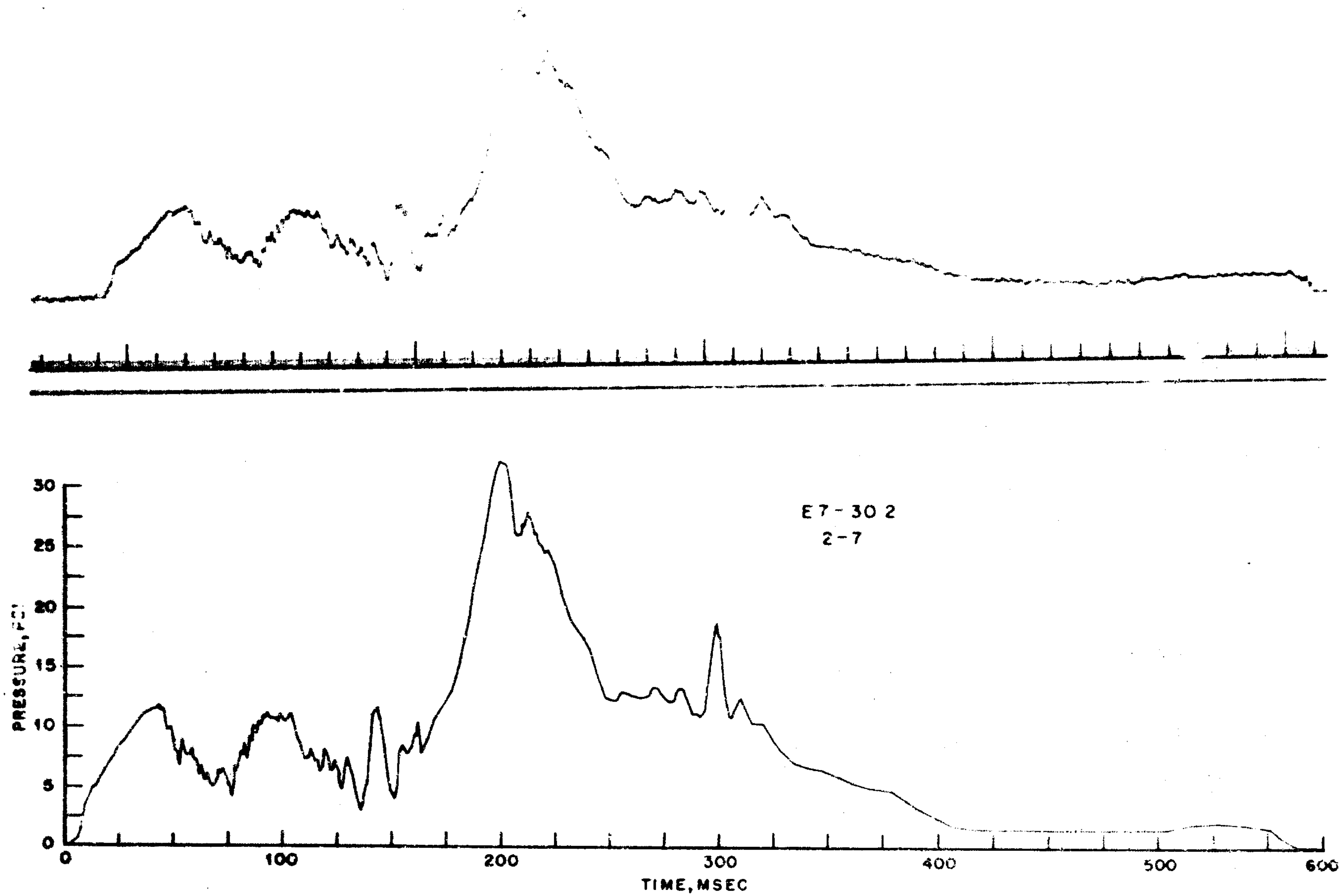


Fig. B.3—Pressure-time record, gauge E7, stations 30.2/2.00.

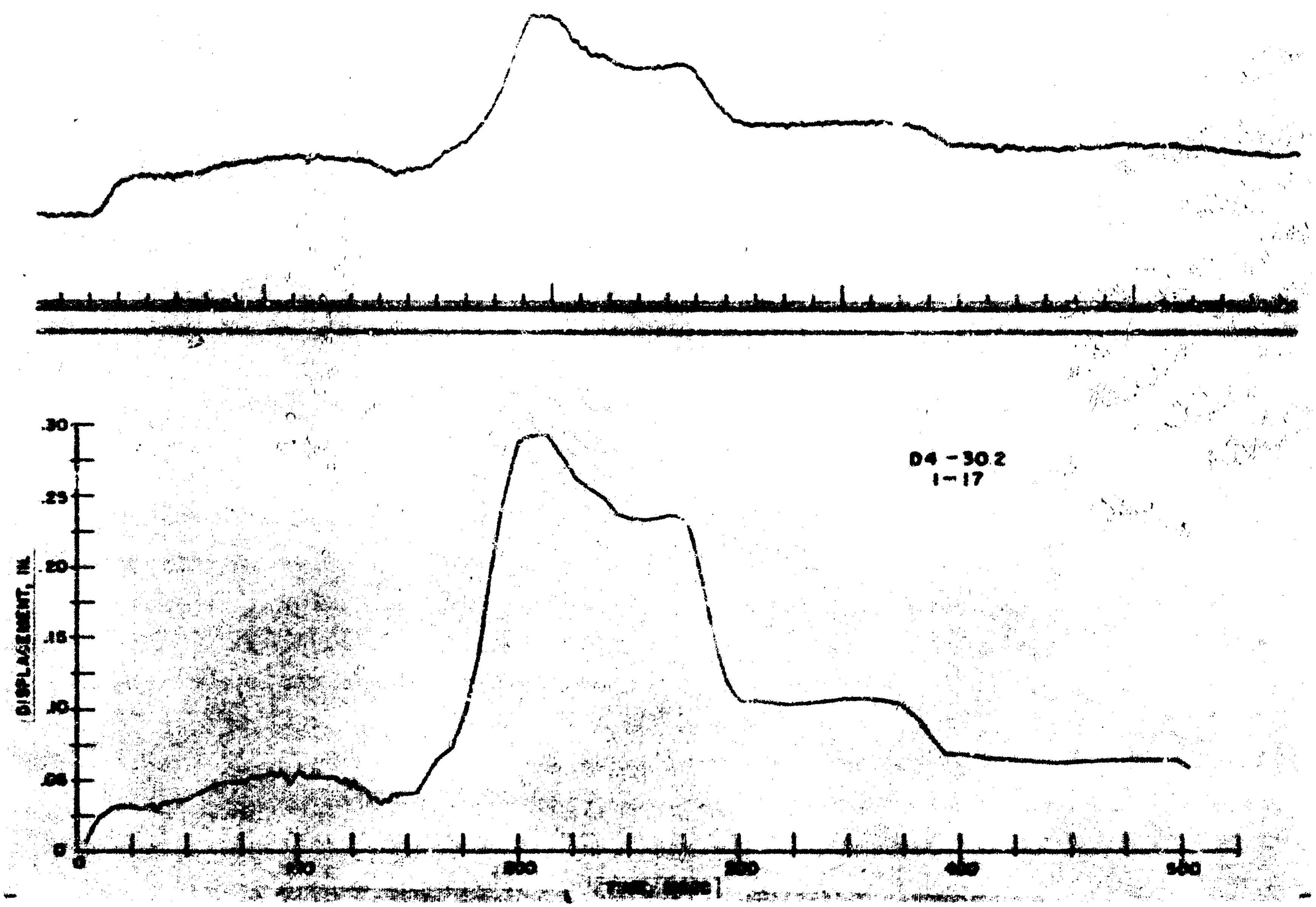


Fig. B.4—Displacement-time record, gauge D4, stations 30.2/2.00.

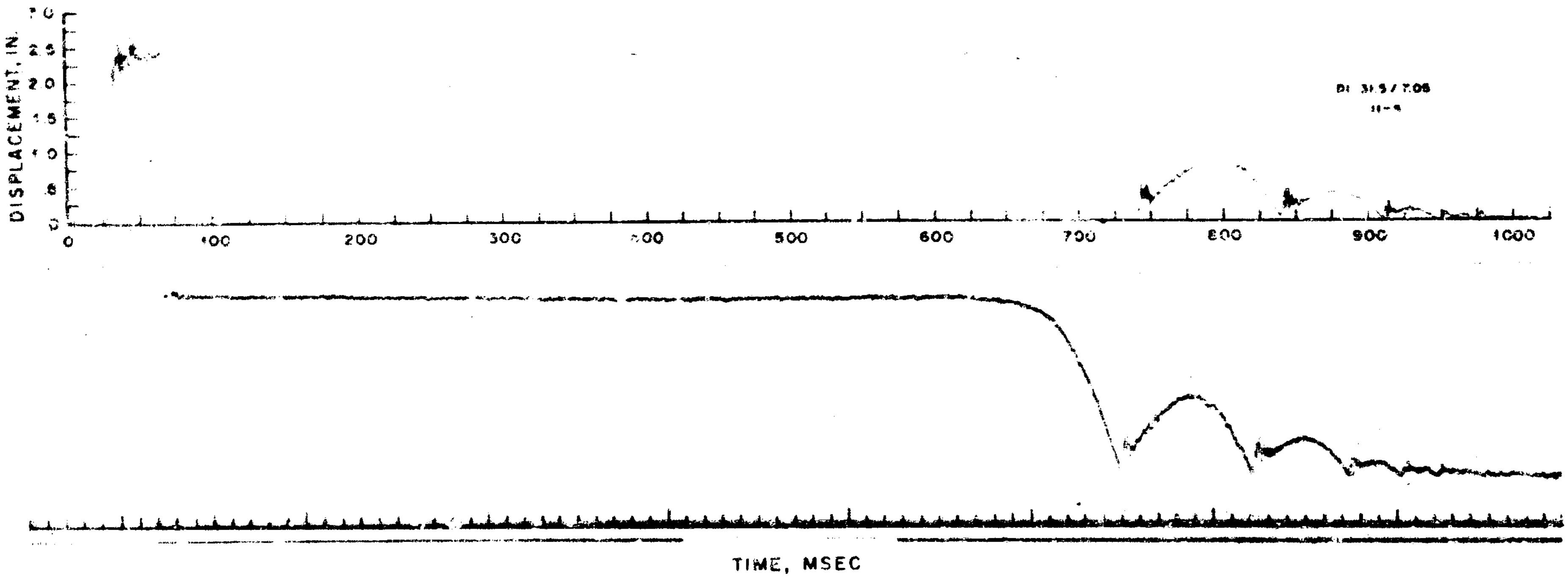


Fig. B.5—Displacement-time record, gauge D1, stations 31.5/7.05.

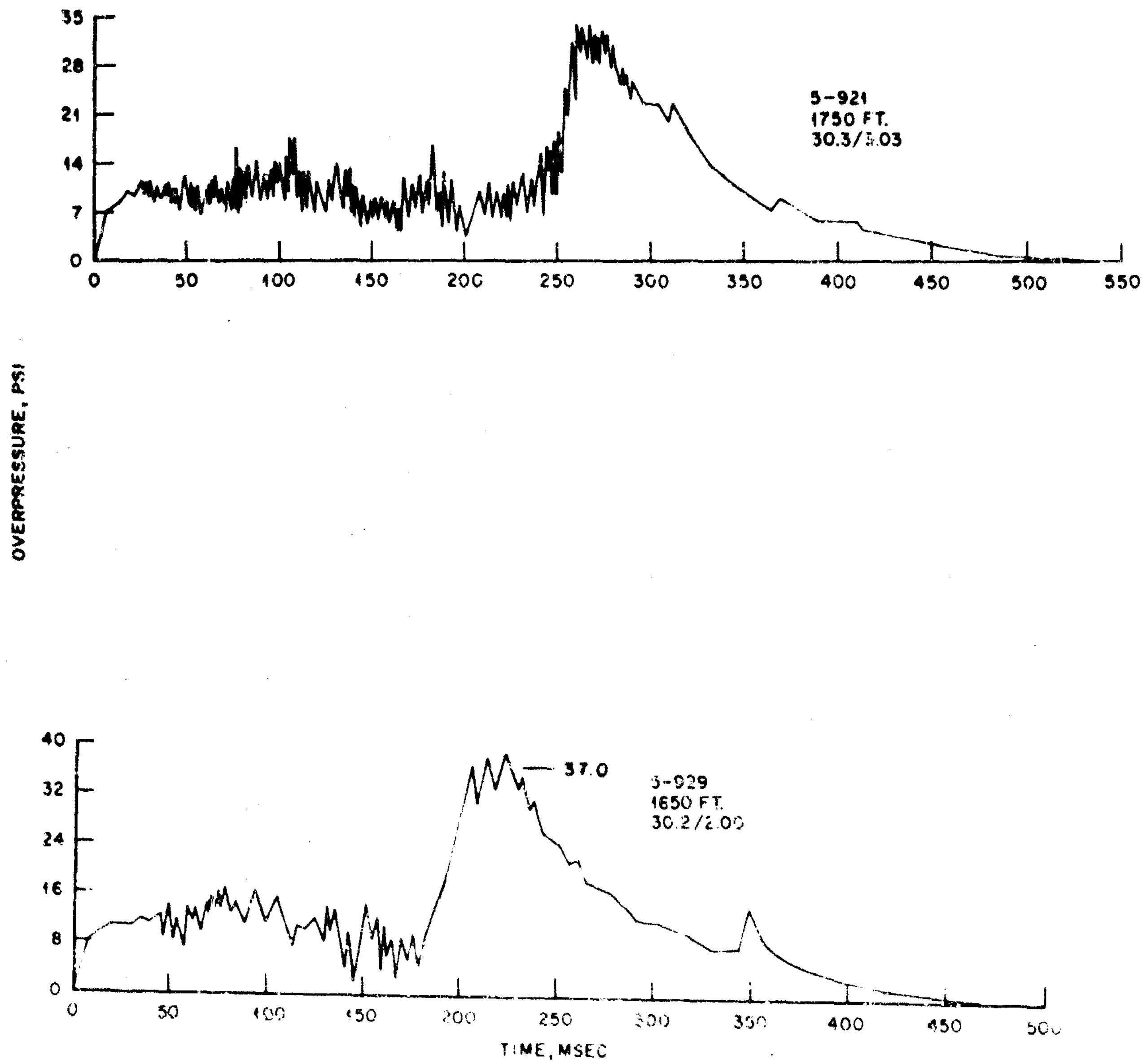


Fig. B.6—Overpressure-time records, gauges outside 30.2/2.00 and 30.3/3.03.

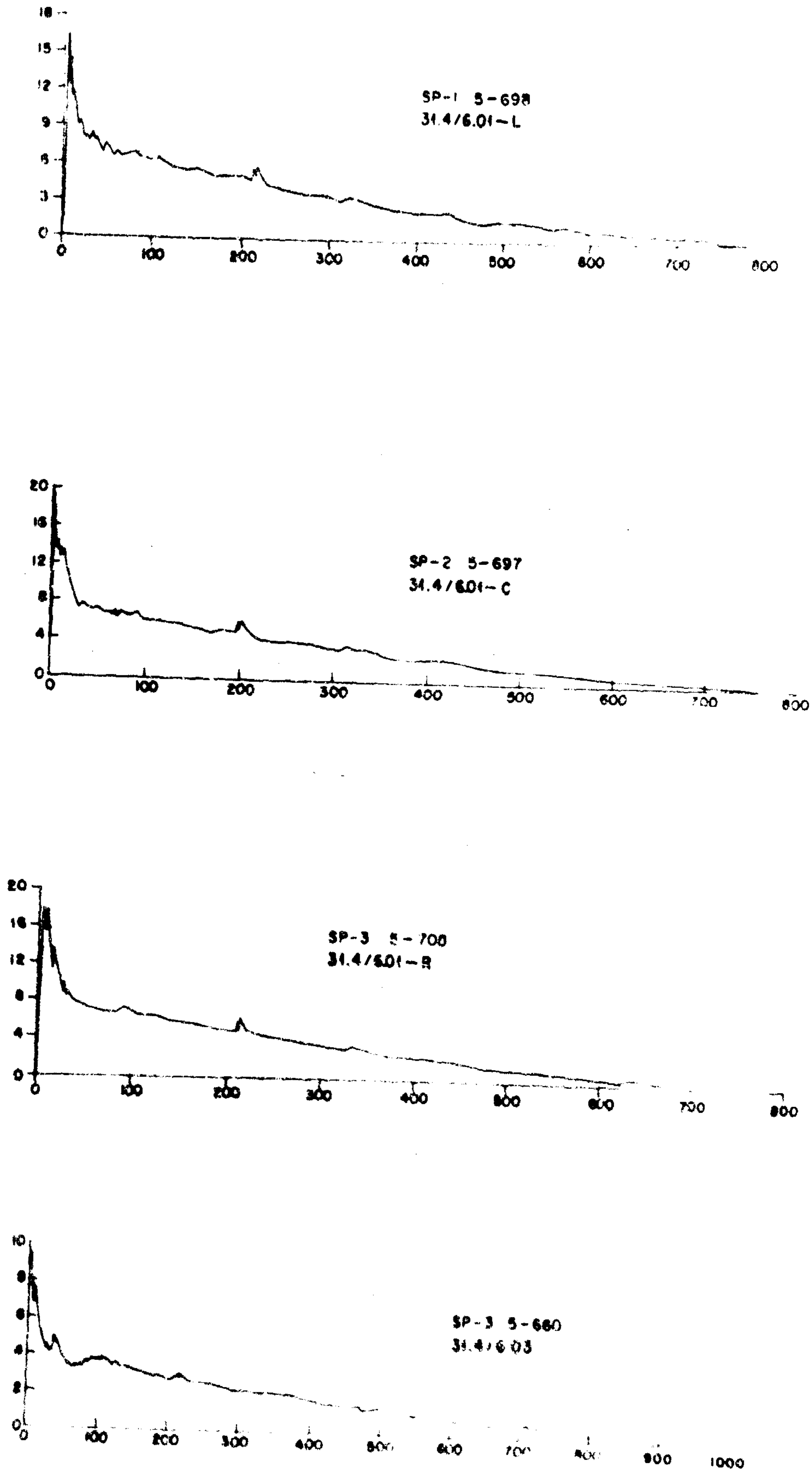


Fig. B.7—Overpressure-time records, gauges outside stations 31.4/6.01/6.03.

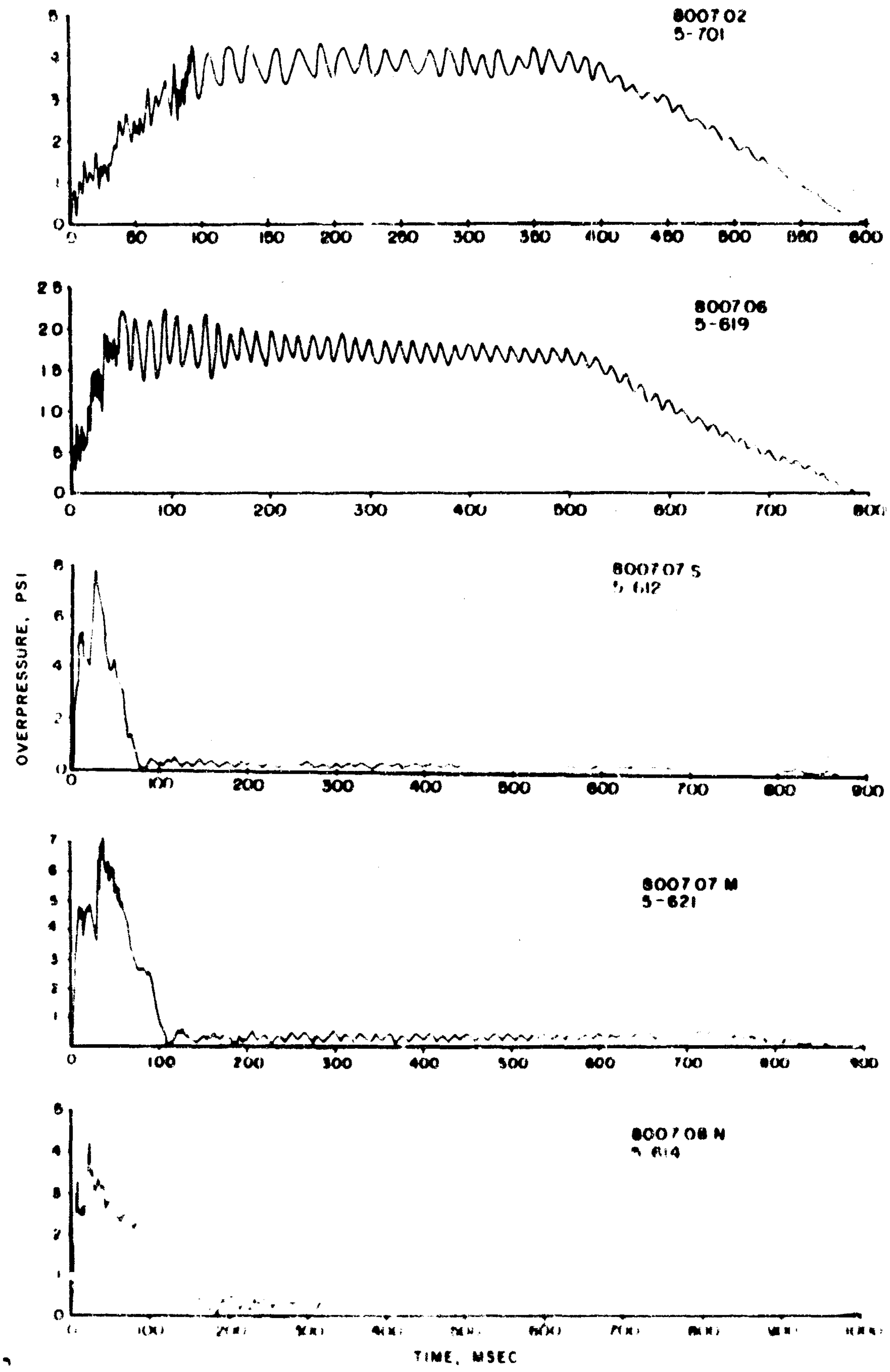


Fig. B.8—Overpressure-time records, gauges inside valves, stations 31.5/7.02, 7.06, 7.07, 7.08.

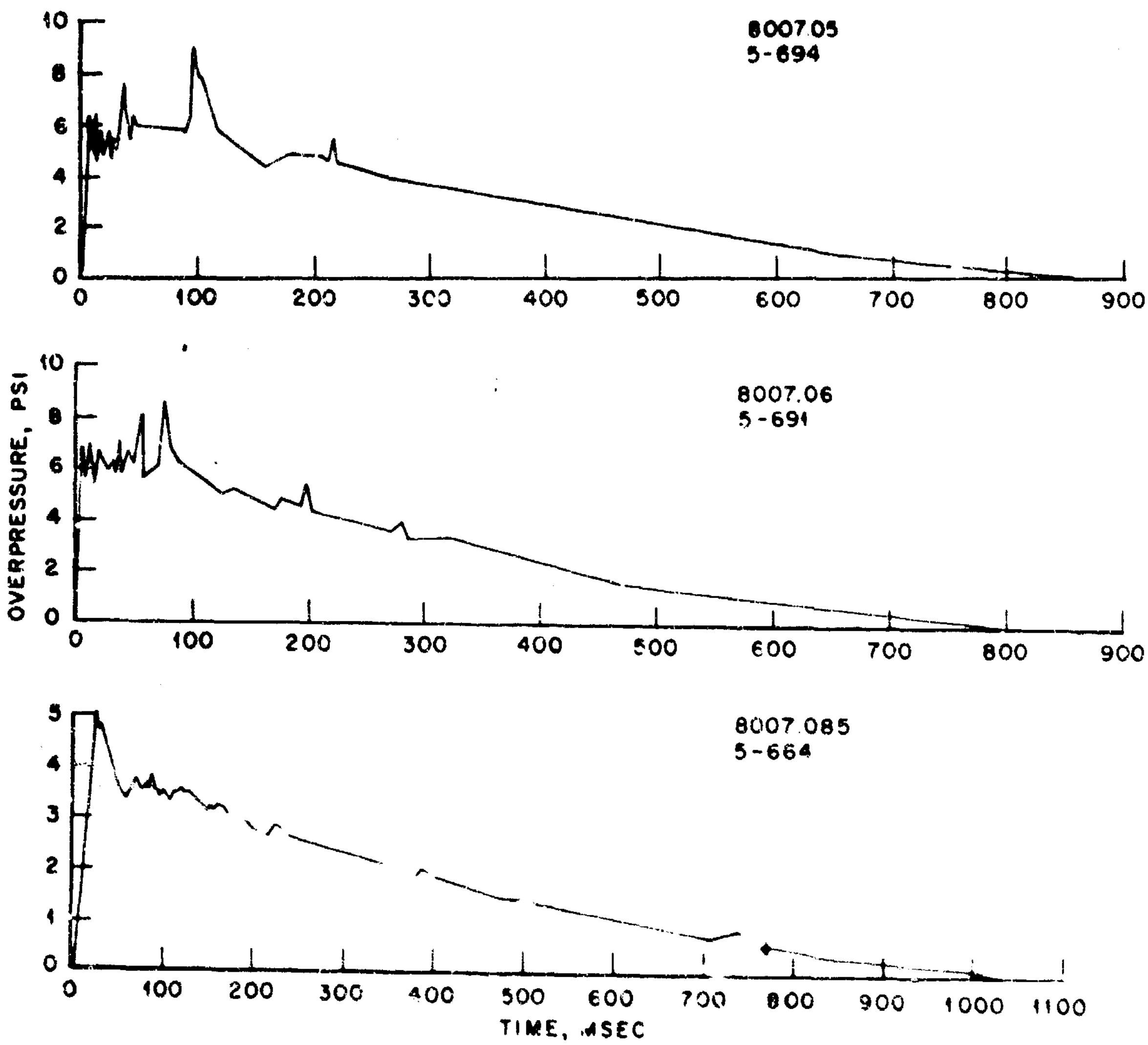


Fig. B.9—Overpressure-time records, gauges outside valves, stations 31.5/7.05/7.06/7.08.

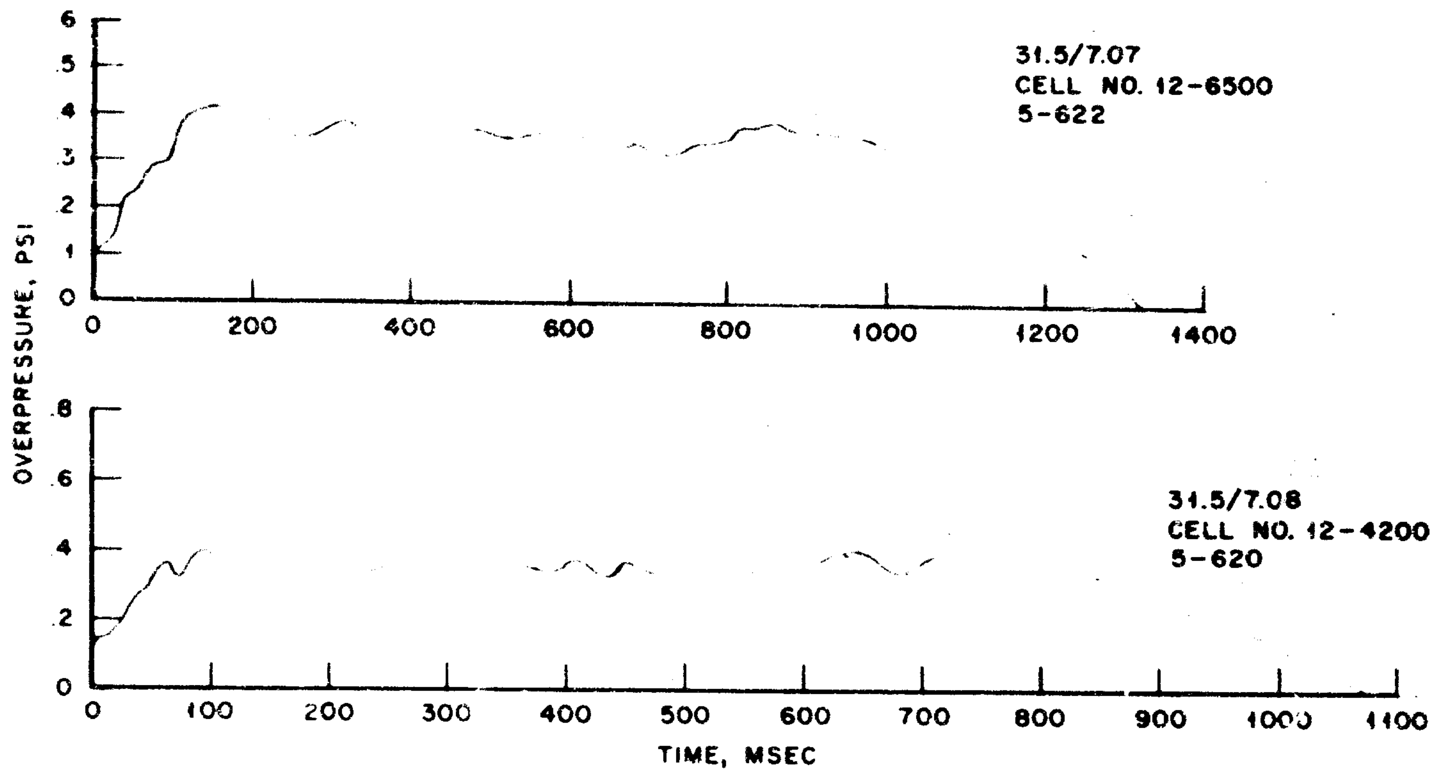


Fig. B.10—Overpressure-time records, SP gauges inside stations 31.5/7.07/7.08.

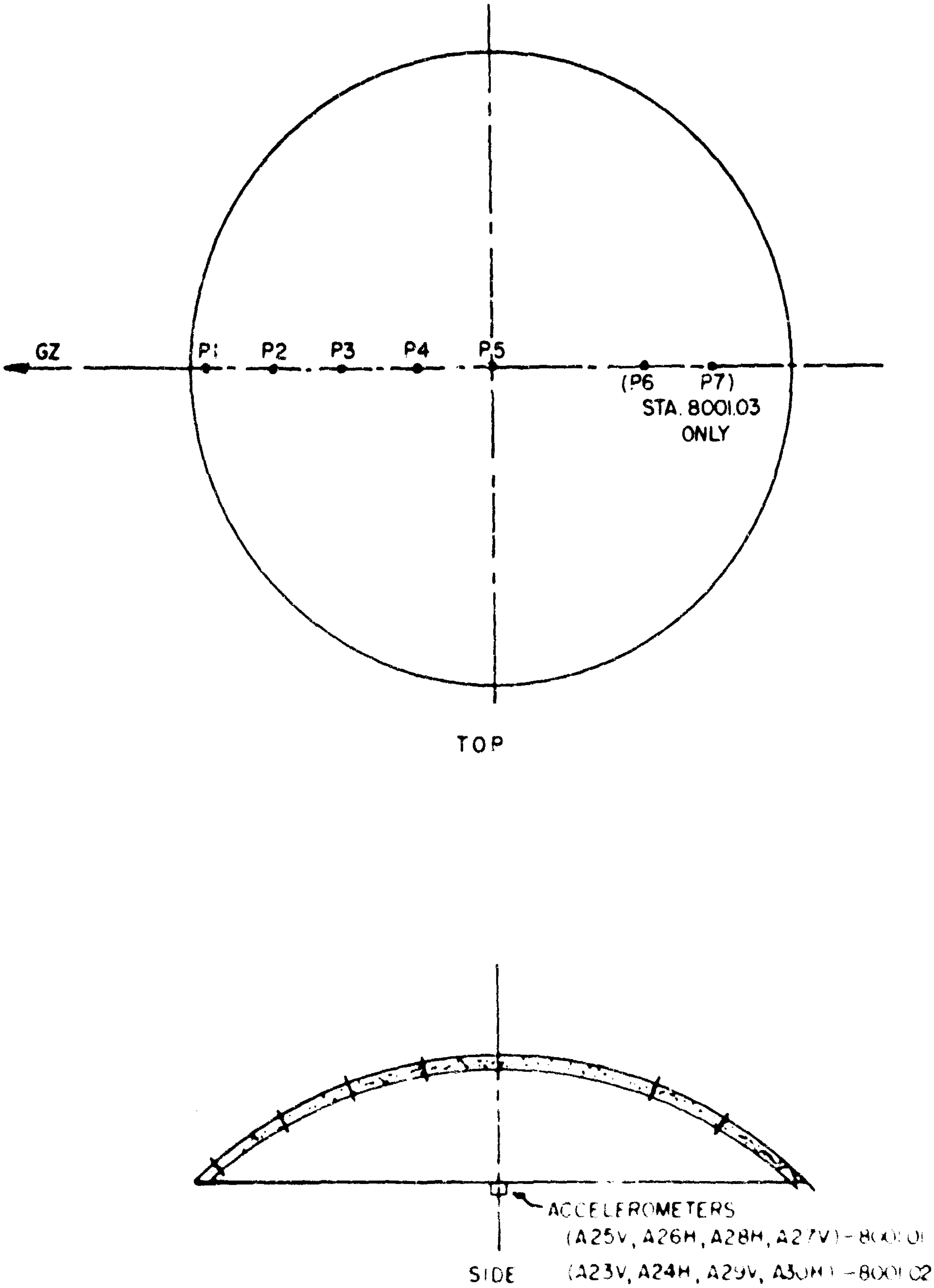


Fig. B 11 — Gage locations for stations 8001, 1.01, 1.02, 1.03

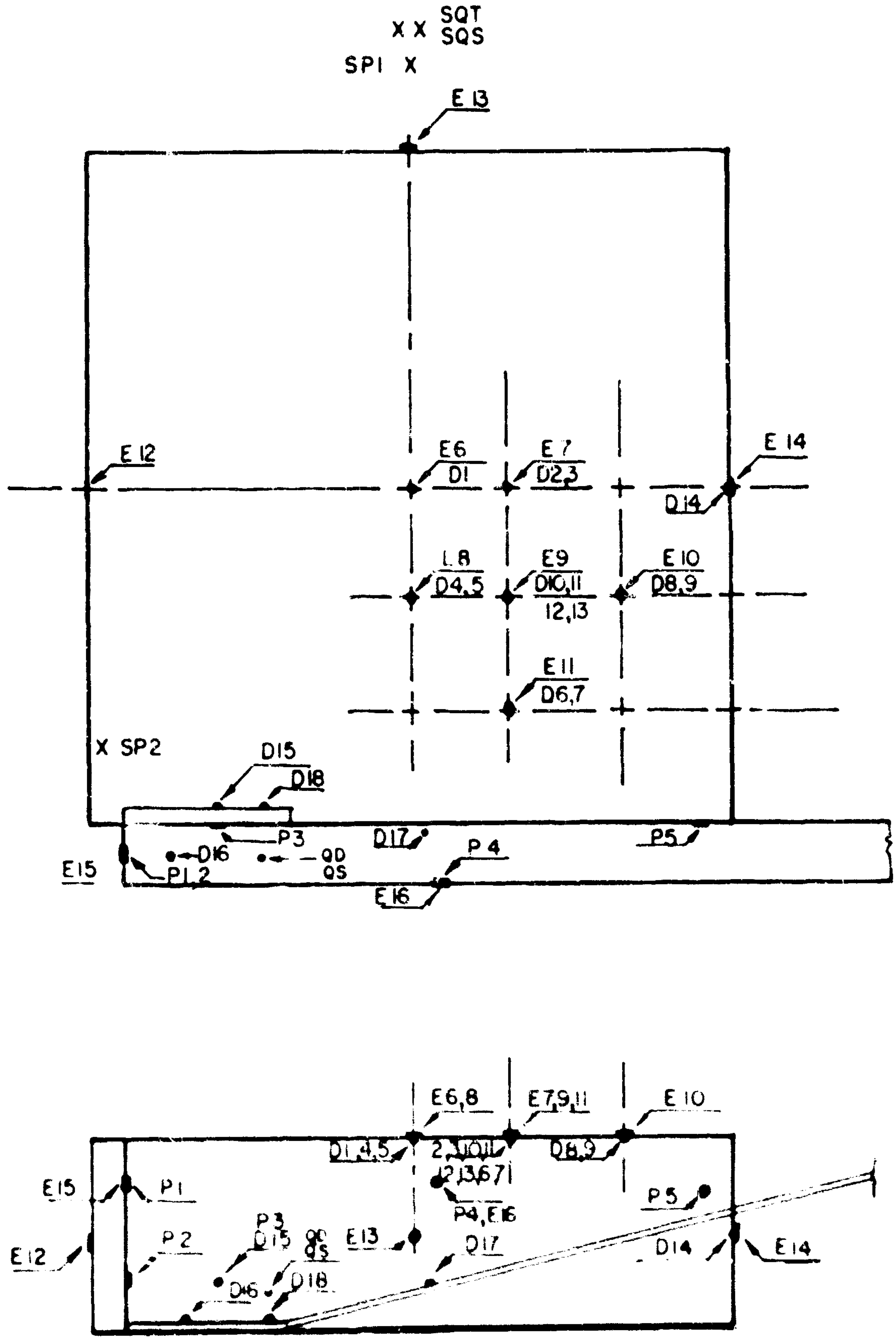


Fig. B.12—Gauge locations for structure 30.2.2.00

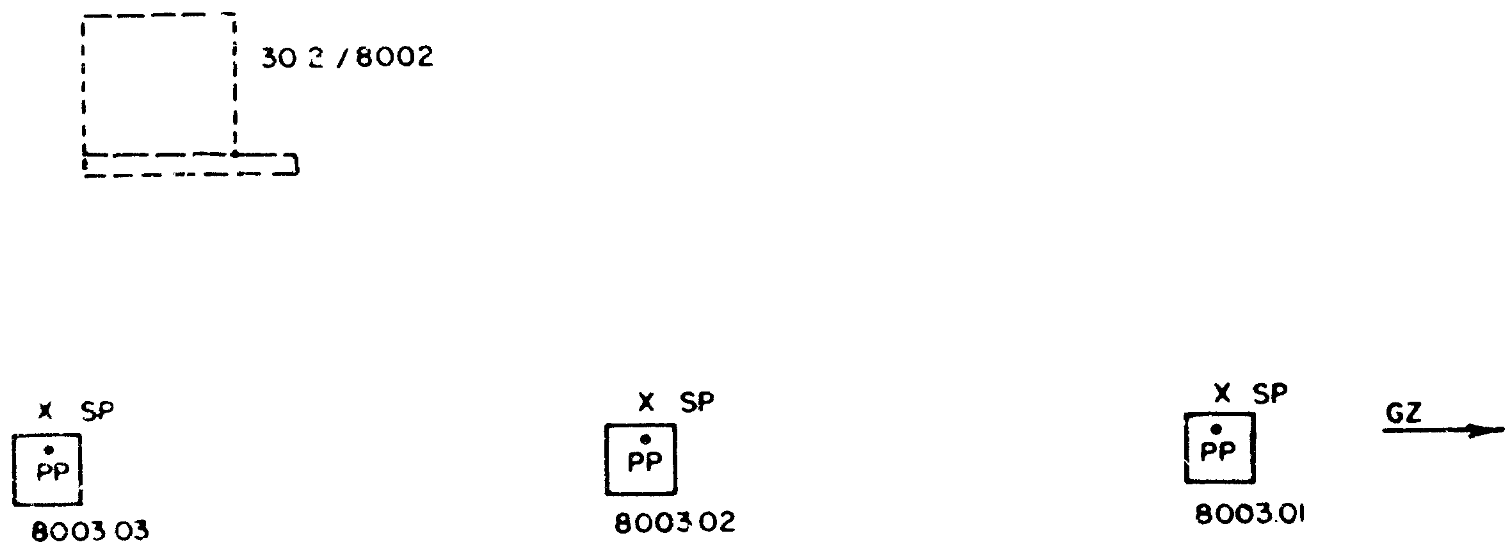


Fig. B 13—Gauge locations for stations 30.3/3.01/3.02/3.03.

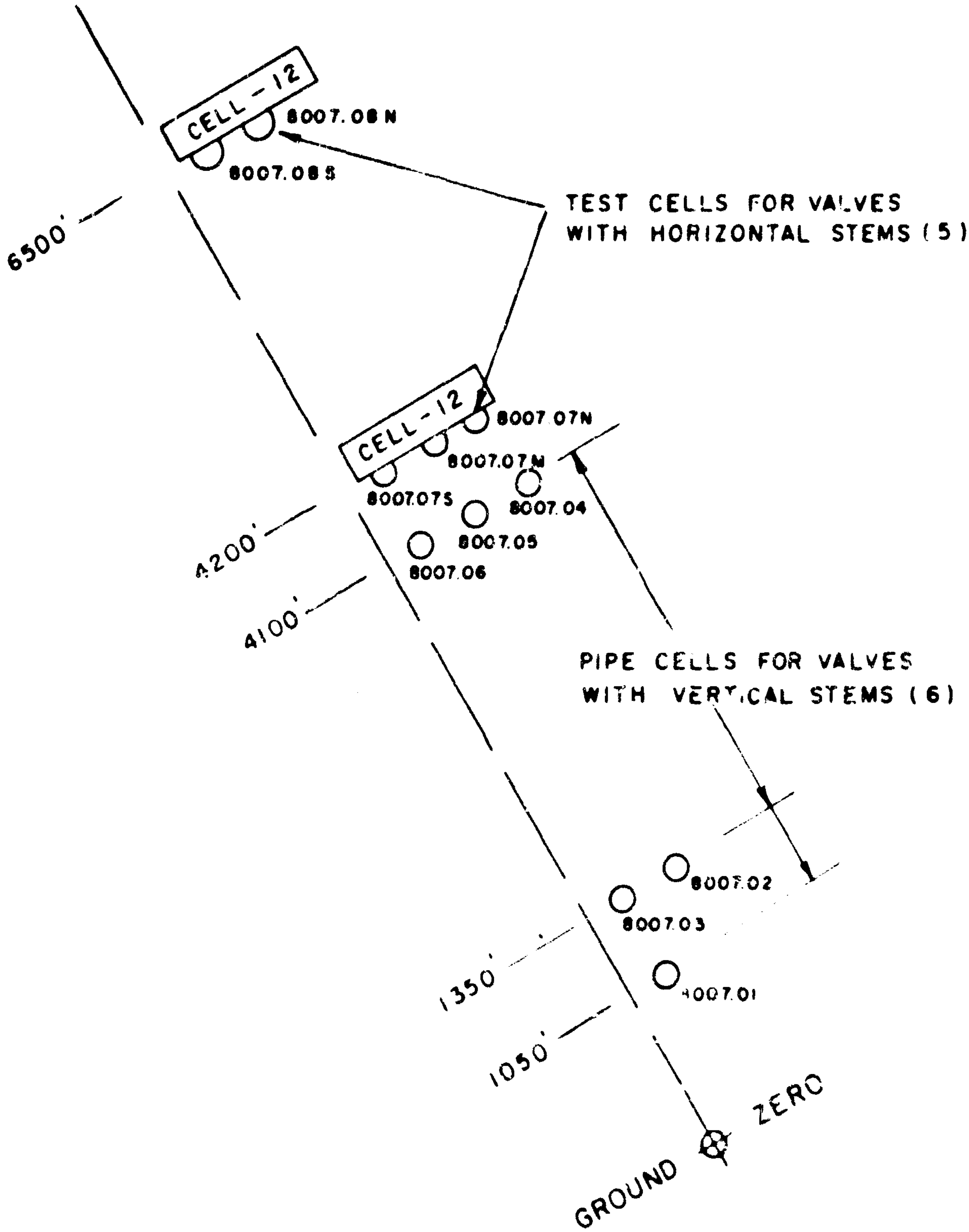


Fig. B 14—Gauge locations for Project 31.5 structures